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Contents

Use of Two Concepts of the Value of Time

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•AS THE DEMANDS for highway facilities have increased with the years, it has become increasingly recognized that economic analyses of proposed highway improvement projects can provide valuable assistance in making rational decisions about the expenditure of public funds. In the very early days of highway construction, decisions were based, to a considerable extent on qualitative judgments; frequently, the only economic data available were estimates of highway construction costs.

In the 1920's, economic calculations began to take into account not only the expenditures of highway agencies (such as those for construction and maintenance of improved highways) but also the expenditures of the highway traveler (such as those for fuel, oil, and vehicle maintenance). When a highway improvement would result in reductions in user costs, these user benefits could be compared with the highway agency costs to obtain an evaluation of the total transportation costs that could be associated with the improvement.

Today, as then, one of the most important user benefits of new highway construction is savings in travel time for the occupants of passenger cars. To recognize the effect of these time savings in economic calculations, it is necessary to convert the savings in hours to a dollar amount. The factor used to make this conversion is called the value of time.

Thus, with the use of a value of time factor, benefit calculations include not only the out-of-pocket costs of vehicle operation, but a monetary evaluation of time savings as well.

This paper examines the meaning and the importance of the "willingness to pay" concept of the value of time; describes a newly developed concept of the economic worth of time savings, which is called the "cost of time"; and compares the use of the "willingness to pay" and "cost of time" concepts in making economic decisions on highway improvement projects. The primary intent is to demonstrate how the cost of time concept can be used to make better decisions in analyzing alternative highway designs and locations, and in formulating highway programs.

In this paper, the factors used in economic analysis have been combined into three parameters:

1. The annual highway cost, which includes the equivalent uniform annual capital or construction cost and the annual highway maintenance cost.
2. The annual user cost, which includes vehicle running costs, time costs for commercial vehicles, and accident costs.
3. The annual travel time for passenger cars.

Throughout the paper, it is assumed that the highway and user costs and the travel time have been accurately determined, and that the economic worth of savings in travel time is the variable factor of interest. The term "value of time" is used to describe the factor for converting hours to dollars in economic analyses. The terms "willingness to pay" and "cost of time" refer to two concepts or approaches to estimating a value of time.

WILLINGNESS TO PAY AS A VALUE OF TIME

For some three decades, highway engineers and economists have been concerned with the problem of measuring the economic value of savings in travel time to the oc-

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cupants of passenger cars. With few exceptions, studies of the economic worth of time have focused on the concept of value as opposed to the concept of cost. The most common concept of the value of time is defined as the maximum number of dollars that the potential users of an improved highway are willing to pay for an hour's saving in travel time. This user-oriented "willingness to pay" concept is similar to "opportunity cost" in economics, because both concepts depend on an evaluation of the alternative opportunities for the use of that time.

It is recognized that the willingness to pay is a variable quantity, dependent on the individual and the situation. Hereafter, the term "willingness to pay" will be used to describe a measure of the central tendency of the distribution of the maximum willingness to pay for time savings.

To illustrate the willingness to pay definition of the value of time, the benefit-cost ratio computation of economic worth of a highway improvement proposal is considered in simplified form (1) to be

$$R = \frac{V\,\Delta t + \Delta u}{\Delta h} \tag{1}$$

in which

R = benefit-cost ratio;
V = value of time, in dollars per passenger car hour;
Δt = savings in annual travel time, in passenger car hours ($t_{existing} - t_{proposed}$);
Δu = savings in annual user costs, in dollars ($u_{existing} - u_{proposed}$); and
Δh = increase in annual highway costs, in dollars ($h_{proposed} - h_{existing}$).

A benefit-cost ratio of 1.0 indicates that the proposal is a break-even one — the benefits are equal to the costs. However, another way of viewing the 1.0 benefit-cost ratio is that passenger car occupants would, if the project were accomplished, be paying the maximum amount that they are willing to pay for the estimated time savings, assuming that the value of time used is a valid measure of maximum willingness.

The value of time is a highly important factor, for a significant proportion of highway improvement proposals cannot be economically justified without converting passenger car time savings to a dollar value. In doing so, the value of time chosen can have a major effect on total benefits.

The effect that the value of time has on benefit-cost ratios is shown in Figure 1. The benefit-cost ratios for three hypothetical improvement proposals (A, B, and C) are plotted as a function of the value of time used in calculating the ratio. Each proposal is represented by a straight line, with a higher benefit-cost ratio resulting from the use of a higher value of time. As an example, if a value of time less than V_1 is used in the calculation, proposal C will have a benefit-cost ratio less than 1.0; that is, it will not be economically justifiable. Figure 1 also shows another characteristic of many improvement proposals — with increases in the value of time, the benefit-cost ratio increases significantly.

Not only does the value of time that is chosen have a significant effect on the justification of a single proposal, it also can affect the relative ranking of competing proposals. In Figure 1, proposal C will have the highest benefit-cost ratio if a value of time less than V_2 is used. If a value between V_2 and V_3 is used, pro-

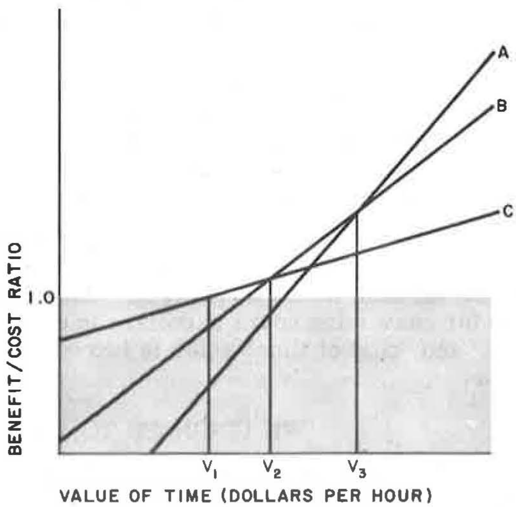

Figure 1. Benefit-cost ratios vs the value of time.

posal B will be favored, and if a value of time greater than V_3 is used, proposal A will be favored. In many situations, the lines that can be plotted for alternative proposals do not cross each other as shown in the figure, and thus different values of time will have no effect in determining the most desirable project. However, in many other situations, the lines do cross. To select the best project in these situations, the value of time must be accurately determined if there is any reason to believe that it may lie somewhere in the vicinity of the crossover values.

Present knowledge about the numerical value that should be associated with time savings is relatively poor. As a matter of fact, the most commonly used value of time ($1.55 per hr) is recommended in the Red Book (1, p. 126) as that value that is "representative of current opinion for a logical and practical value." The inadequate basis for the values now used is clearly recognized, and the number of investigations into this problem have increased in recent years.

COST OF TIME CONCEPT

The willingness to pay concept is not the only way of viewing the worth of time. Just as any commodity has a utility and a cost — and the commodity is desirable if its utility is greater than its cost — time savings also have a utility (a maximum willingness to pay) and a cost.

Although a single willingness to pay might be used to evaluate all projects of a certain class, the costs of specific projects may differ. Each project will have its own cost of time.

The cost of time concept is defined as the actual cost of providing time savings on a specific project. For each project, the cost of time, C, may be computed as

$$C = \frac{\Delta h - \Delta u}{\Delta t} \tag{2}$$

The difference ($\Delta h - \Delta u$) may be considered as the "net change in annual transportation costs" of a given project or an aggregation of projects. This transportation cost concept allows the total dollar expenditures from two sources (highway agencies and highway users) to be considered together.

If the benefit-cost ratio for a certain project is 1.0, the cost of time is equal to the willingness to pay for time savings. The project will "break even." In symbolic terms, if

$$R = 1 = \frac{V\,\Delta t + \Delta u}{\Delta h}$$

then

$$V = \frac{\Delta h - \Delta u}{\Delta t}$$

or

$$V = C$$

In relatively few cases, however, are the benefit-cost ratios of selected highway improvement projects equal to one. The ratios are frequently substantially greater than one. Therefore, the actual cost of time savings for specific projects is generally some substantial amount less per hour than the willingness to pay value used in analyzing the improvement; i. e., if

$$R = \frac{V\,\Delta t + \Delta u}{\Delta h} > 1$$

then

$$V\,\Delta t + \Delta u > \Delta h$$

and from Eq. 2,

$$\Delta h = C\,\Delta t + \Delta u$$

then

$$V\,\Delta t + \Delta u > C\,\Delta t + \Delta u$$

or

$$C < V$$

Thus, with a benefit-cost ratio greater than 1.0, the estimates, in effect, indicate that the highway user would actually be paying somewhat less for time savings than the estimated value that he is willing to pay. To illustrate this point, the benefit-cost ratio and the cost of time were computed from data available on a number of projects (Table 1).

Most highway projects result in time savings and in increased highway cost. Therefore, in the computation of benefit-cost ratios, Δt is normally positive and Δh is normally positive. These restrictions are not necessary for the concepts presented in this paper. However, for simplicity of the immediate algebra, it is assumed that $\Delta h > 0$ and $\Delta t > 0$; i. e., that both highway costs and time savings are greater than zero.

OBJECTIVES OF HIGHWAY ECONOMIC ANALYSIS

Next, the usefulness of the concepts of the willingness to pay and the cost of time in meeting three objectives of highway economic analysis are examined. These objectives can be stated as follows:

1. Justifying highway improvement projects (comparing benefits with costs);
2. Formulating highway programs; and
3. Establishing tax rates and budget levels.

The justification of highway projects involves a comparison of the economic features of a proposed project with some predetermined standard. The formulation of highway programs is concerned with the fitting of economically justifiable proposals into a construction program. The establishment of tax rates and budget levels can be thought of as providing the amount of improvement that the highway users demand — a simple statement of an extremely complex problem.

First, a hypothetical world is considered — a world in which all considerations are expressible in economic terms, in which there are no irreducibles or "political" considerations, in which highway decisions are based purely on known economic data. In this world, it is assumed that the willingness to pay is a known constant, and, for each project under consideration, all other economic values would have been accurately determined.

A highway district is considered in this hypothetical world. The net dollar costs (Δh - Δu) and time savings (Δt) for proposed improvement projects can be shown graphically. Figure 2 shows the net change in annual transportation costs for various

TABLE 1

COMPARISON OF VALUE AND COST OF TIME FOR SELECTED PROJECTS[1]

Location of Project		Assumed Value of Time ($ per hr)	Resulting Benefit-Cost Ratio	Actual Cost of Time[2] ($ per hr)
State	Place			
Calif.	Baxter Creek	1.56	1.18	+1.21
	Butte County	1.56	1.59	+0.41
	King City	1.56	5.532	-1.45
	Sacramento	1.56	1.42	+0.76
	Salinas	1.56	1.176	+1.085
	Vacaville	1.20	4.6	-0.65
Conn.	Bridgeport	0.82	3.73	+0.16
	Norwalk	0.80	2.49	+0.38
Idaho	Idaho Forest	0.60	1.60	+0.08
	Moxie River	1.35	7.79	-0.33
Ky.	Louisville	1.35	9.60	-0.89
La.	Baton Rouge	1.35	2.43	-0.89
Mont.	Reas Pass	0.60	0.87	+1.10

[1] Value of time savings, plus user cost savings, minus highway cost increase.
[2] Source: Stanford Research Institute.

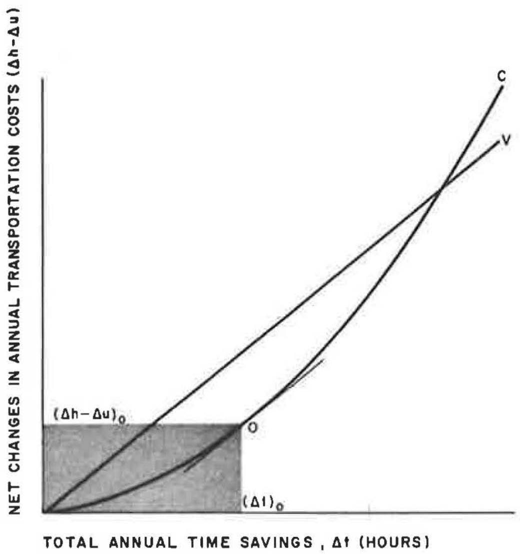

Figure 2. Net change in annual transportation costs vs total annual time savings.

amounts of highway improvements on the ordinate, and the resulting annual time savings on the abscissa. Individual projects or sets of projects could be plotted as points on this graph. Two curves are shown to indicate the willingness to pay value of time and the cost of time. The willingness to pay curve, V, for the district is plotted as a straight line, which indicates that the willingness to pay for time savings is independent of the amount of time saved. Those points plotted for projects or for sets of projects that lie below this curve would be considered desirable; those above, undesirable. (In reality, the willingness to pay time curve may be more complex, but its exact shape is not of great importance to this argument.) The cost-of-time curve, C, is a cumulative curve of the costs of time for various combinations of the available highway projects. If projects are arrayed in order of increasing cost of time, and cumulative values are plotted, the resulting curve will be concave from the top of the graph, and the incremental cost of time will increase as more time is saved. This curve, then, is the locus of the best available project sets. No points plotted for project sets lie below the curve. (Another cost of time curve for a hypothetical set of discrete projects will be shown in Fig. 3.)

The graphical solution to this hypothetical world problem is simple: time savings should be purchased until the last increment of time savings is equal to the willingness to pay for time savings. At this point, which is shown at 0 on the graph, the slopes of the willingness to pay value of time curve and the cost of time curve are equal. Further savings of time would cost more than highway users are willing to pay; i. e., the incremental cost of time would be greater than the maximum willingness. The total annual time savings that should be provided are $(\Delta t)_0$. The net change in transportation costs that is indicated is $(\Delta h - \Delta u)_0$. This dollar cost is a composite of increased highway costs and savings in user costs. The correct budget for new construction in this hypothetical district would be equal to the highway cost component (converted to a present worth) of the total dollar costs. (If maintenance costs are included in the highway cost estimates, the budget would be computed by converting the annual capital (construction) cost component of Δh to a present worth, and adding the annual increased maintenance costs.)

Thus, in this hypothetical world, projects would be justifiable if their cost of time were less than the willingness to pay; the correct program would consist of all projects that are justifiable; and the tax rates would be adjusted to provide the amount of funds required to complete the program comprised of all justifiable projects.

The real world is far different from this hypothetical (and superficially described) world. In the first place, decisions of justification, program formulation, and taxation are based in part on considerations that cannot be reduced to economic terms. Secondly, the economic calculations may be in error because of errors in input data. Of specific interest to this paper are two problems:

1. It is difficult to establish tax rates and budget levels solely on economic grounds.
2. The willingness to pay is not known with precision.

Tax Rates and Budget Levels Difficult to Establish

In the legislative process of fixing taxes and in the resulting administrative process of establishing budgets, many complex and nonquantifiable considerations apply.

(The term "budget" in this report refers not to the estimated or approved expenditure for a single project, but to the total amount of funds that is allocated to an agency for allocation to many projects.) Tax rates are frequently established on the basis of detailed highway needs studies, but these studies are based to a considerable degree on engineering judgment, because accurate economic data are not available. Once the tax rates are fixed, legislative apportionments of funds to highway types and to geographical areas cannot be justified by indisputable economic data. Finally, the allocation of the total estimated revenue to various activities within a highway agency is similarly based at least in part on nonquantitative considerations. It may be utopian to hope that the "correct" taxes and budgets can ever be fixed with accuracy.

Nevertheless, tax rates and budgets are economic realities that most highway planners must face. Highway programs must be formulated within the expectation of total revenues. No matter how properly or improperly the tax rates and budget levels are established, they must be recognized. The highway planner must therefore concern himself with developing the best possible procedures for selecting among alternative construction proposals within this constraint.

Willingness to Pay Not Accurately Known

Highway agencies, in the process of analyzing the economics of improvement proposals, may estimate many traffic and cost factors for the alternatives being considered. The estimate of each factor is subject to some error, and errors in the estimates may result in errors in the conclusions drawn from economic calculations. Some of the factors that are commonly estimated for such calculations are listed in approximate order of accuracy from most to least.

1. Project length.
2. Per mile running costs for both passenger cars and trucks.
3. Travel time for both passenger cars and trucks.
4. Average daily traffic.
5. Capital (construction) cost.
6. Annual highway maintenance cost.
7. Annual accident rate.
8. Minimum attractive rate of return.
9. Rate of traffic growth.
10. Study period (number of years for analysis).
11. Personal injury cost.
12. Willingness to pay value of time.
13. Cost of a human life.

Because of the errors inherent in estimates of these factors, an economic analysis must be concerned with more than the simple combination of all the factors into some formulation of economic worth. It is also necessary to evaluate the effect of possible errors on the calculation; in other words, to perform a sensitivity analysis. This consideration is basic to the principles of engineering economy and has been discussed in detail by Grant and Oglesby (2).

In some methods of analysis (e. g., benefit-cost ratio, equivalent annual cost, present worth), all factors must be known before the calculation can be made. In another method used to calculate break-even point or rate of return, all factors except a rate of return must be known, and the calculation is made to determine the rate of return.

It is possible to design a method of analysis, similar to a rate of return calculation, in which all factors except the willingness to pay must be known. This calculation is made in terms of the cost of time.

If the calculation of the economic worth of a particular project were made in terms of the cost of time, it appears that significantly increased insight could be gained as to the importance of this factor, and that project priority lists could be prepared which do not depend so heavily on a willingness to pay value of time on which little confidence can be placed. Even though some value of time has been used for years in economic analysis, the fact remains that relatively little confidence can be placed on the willingness to pay value which is chosen for the calculations. At least, most other factors (including a minimum attractive rate of return) can be estimated with more precision than the willingness to pay.

The remainder of this paper compares use of the willingness to pay value of time with use of the cost of time for identification of project priorities within the context of a budgetary constraint.

SELECTION OF HIGHWAY PROJECTS USING WILLINGNESS TO PAY VALUE OF TIME

The concept of the willingness to pay is almost universally used to evaluate the economic consequences of highway improvements. After compiling the basic project data (such as highway cost, user cost, and travel time) and separately estimating or assuming a willingness to pay, the analytical methods used to evaluate feasible alternatives include computation of benefit-cost ratios, equivalent annual costs, or rates of return.

As discussed previously, errors in input data may cause errors in the project selection process in spite of the validity of the analytical methods used. In this section, the effect of various willingness to pay values on the project selection process are examined in detail.

Current methods of analysis can best be illustrated by an example. Table 2 gives a number of hypothetical highway improvement proposals. At each of four different locations within the highway district, either three or four mutually exclusive improvement proposals are presented for consideration (14 in all). It is assumed that the total budget which is allocated to the district for the year for construction of new projects is $11.7 million. The equivalent annual capital cost of this $11.7 million budget, based on 7 percent interest and 20 years, is $1.1 million. All subsequent comparisons are made on the basis of this $1.1 million equivalent annual capital cost.

TABLE 2

HYPOTHETICAL HIGHWAY IMPROVEMENT PROPOSALS, CHANGE OVER EXISTING CONDITION[a]

Location Number	Cost and Time Factors	Proposals[b]			
		1	2	3	4
1	Increase in annual highway cost ($)	+0.2	+0.7	+1.5	+2.3
	Savings in annual user cost ($)	-0.1	-0.2	+0.7	+1.7
	Savings in annual travel time (hr)	+1.1	+1.4	+2.0	+1.9
2	Increase in annual highway cost ($)	+2.6	+4.7	+9.5	+12.0
	Savings in annual user cost ($)	+0.2	+0.3	+0.3	+0.8
	Savings in annual travel time (hr)	+5.3	+7.7	+9.2	+9.9
3	Increase in annual highway cost ($)	+2.1	+3.5	+6.2	--
	Savings in annual user cost ($)	+3.7	+2.8	+0.1	--
	Savings in annual travel time (hr)	+0.5	+3.3	+6.1	--
4	Increase in annual highway cost ($)	+1.1	+2.1	+3.8	--
	Savings in annual user cost ($)	+1.6	-0.5	-4.5	--
	Savings in annual travel time (hr)	+2.6	+8.1	+12.2	--

[a]Estimates of highway and user costs are stated in terms of equivalent uniform annual series. Changes of travel times are also corrected to an equivalent uniform annual series.

[b]Estimates of dollars and hours in hundreds of thousands.

For each proposal, estimates of economic factors have been summarized in Table 2 in the three categories defined previously. The highway cost is the estimate for capital expenditures, and includes costs of detailed design, land acquisition, and construction, converted to an equivalent annual basis using 7 percent interest and a 20-yr life. (Throughout these examples, it is assumed that the highway cost is composed only of capital (or construction) costs, and that highway maintenance costs are estimated in a separate budget. Thus, annual highway costs in these examples can be directly converted to a present year's budget simply by converting the annual series to a present worth.)

The savings in annual user costs is the difference between the existing user costs and the estimated user costs if the improvement were accomplished. User costs include such items as vehicle running costs, accident costs, and time costs for commercial vehicles (it is assumed that information is available to permit estimating a value of time for commercial vehicles independently). An increase in user costs is indicated by a minus sign. The savings in annual travel time is for passenger cars only. Both user costs and travel times are expressed in equivalent annual figures using the same rate of interest as used to reduce the capital cost to its equivalent annual amount.

An alternative method of handling commercial vehicle time would be to establish an arbitrary weighting factor to convert saving of commercial time to an equivalent number of hours for passenger cars. An equivalent amount of total hours saved could then be computed and converted to dollars by using a value of time for passenger cars.

To demonstrate the possible results of using an inaccurate value of time, the proposals are analyzed with three alternative willingness to pay values of $1.00, $1.50, and $2.00 per hour.

<u>Incremental Procedure</u>

With the data on highway costs, user costs, and travel time thus defined, and willingness to pay values assumed for the analyses, it is now necessary to describe the analytical technique used to select proposals within the limit of the budget. Because of its wide acceptance, the benefit-cost ratio method is used for analyzing these 14 proposals. As pointed out by Winfrey (3) and by Grant and Oglesby (2), incremental investments are justified when the incremental benefits are greater than the incremental costs; the incremental benefit-cost ratio is appropriate for the analysis.

To choose a set of projects using the incremental benefit-cost ratio method, it is necessary to consider all 14 proposals simultaneously. When the alternative proposals must be considered within the context of a budgetary constraint, the incremental analysis must consider all alternatives at all locations in a single analysis. Separate evaluations at separate locations may indicate which proposal will result in the greatest benefit-cost ratio at each location, but cannot provide a basis for selection of improvements at different locations to arrive at maximum gain within the budget constraint. The result of separate analyses is that some locations may receive relatively costly time savings because only costly alternatives were proposed, whereas other locations receive relatively inexpensive time savings because only inexpensive alternatives were proposed.

In many highway agencies, economic analysis frequently affects two stages in highway planning, the two stages being performed by separate organizations. The first stage is frequently called economic analysis in location and design; the second, programing. If there is a budgetary constraint which affects the programing process, the analyses by separate organizations may lead to selection of sets of projects which are not optimal.

The method presented here would result in optimal gain (maximum total benefits), if the actual willingness to pay were known, but the point of the example is to show the effect of various values of the willingness to pay.

An iterative procedure is used, in which the best incremental benefit-cost ratio is chosen among all alternatives at all locations at each iteration. The iterative procedure continues until no further investment opportunities exist that will permit the total expenditure to remain within the budget, with the additional criterion that no proposal will be accepted which has an incremental benefit-cost ratio less than 1.0.

The iterative procedure as described is somewhat cumbersome numerically. The hypothetical highway improvement proposals in Table 2 are considered in Appendix A according to this iterative procedure. At each iteration, the following steps are required:

1. Given the existing situation at the end of the previous iteration, the incremental investment opportunities not yet chosen or rejected are considered. The measure of each alternative is the incremental benefit-cost ratio.
2. From all incremental benefit-cost ratios at all locations, the most attractive alternative (that with the greatest benefit-cost ratio) is selected.
3. The highway cost of the alternative selected is added to a cumulative total highway expenditure schedule. If the alternative selected replaces one at the same location chosen in a previous iteration, the highway cost of the previously chosen alternative is dropped from the highway expenditure schedule.
4. If the revised highway expenditure total is less than the budget, the alternative chosen at this iteration is added to the list of alternatives previously selected, and any previous selection at that location is removed from the schedule.
5. If the revised highway expenditure total exceeds the budget, the alternative selected is rejected at this iteration. The list of alternatives remains the same as at the beginning of the iteration.

Using this procedure with the three values of the willingness to pay, three sets of projects are chosen (Table 3), along with the resulting total change in highway cost, in user cost, and in travel time. Also, at the bottom of the table are the net benefits (value of travel time savings, plus user cost savings, less highway cost).

Using three willingness to pay values to analyze the 14 improvement proposals results in the selection of three different sets of projects to be constructed. Thus, if little confidence is held for the actual willingness to pay, little can be said about the comparative economy of the three sets. Computations of the net benefits, given at the bottom of Table 3, are meaningless because the benefits depend to a considerable extent on the willingness to pay value used in the calculations.

TABLE 3

PROJECTS CHOSEN USING INCREMENTAL BENEFIT-COST RATIOS

Property	Willingness to Pay = $1.00/Hr	Willingness to Pay = $1.50/Hr	Willingness to Pay = $2.00/Hr
Project identification[1]	(1, 4), (2, 1), (3, 2), (4, 2)	(1, 2), (2, 2), (3, 2), (4, 2)	(1, 2), (2, 1), (3, 2), (4, 3)
Savings in travel time (hr)	1,860,000	2,050,000	2,220,000
Value of time saved ($)	1,860,000	2,075,000	4,440,000
Savings in user cost ($)	420,000	240,000	-170,000
Total user savings ($)	2,280,000	3,315,000	4,270,000
Total increase in highway cost ($)	1,050,000	1,100,000	1,060,000
Net benefits (including travel time) ($)	1,230,000	2,215,000	3,210,000

[1] First number in parentheses is location number; second is proposal number.

SELECTION OF HIGHWAY PROJECTS USING COST OF TIME

If little is known about the willingness to pay, errors in project selection may result, as illustrated in the previous section. How, then, can this difficulty be surmounted? The answer lies in a solution for the cost of time. Rather than performing calculations of benefit-cost ratios, equivalent annual costs, or rates of return, a procedure can be devised to evaluate projects in terms of the dollar cost of providing time savings — the cost of time.

The Budget

The cost-of-time procedure would function within a specific budget and would apply to all projects that fall within the scope of that budget. The total money available to a State highway department is apportioned to various uses; for example, to administration of the department and to highway maintenance activities. The remainder of the funds is sometimes distributed (as subbudgets) to geographic divisions within the State. The procedure would apply to a subbudget.

Furthermore, the procedure would apply only to those proposals that are evaluated in economic terms. Some projects are undertaken without an economic justification, because they cannot be evaluated on economic terms, or because they are deemed desirable to provide continuity within the highway system, or for other reasons. The cost of time procedure would apply to the subbudget or budgets that remain: to the specific geographical area and class of budgetary expenditure to which a set of proposals and their costs may be associated, all requiring economic justification.

The determination of the budget to be analyzed also involves the time-phasing of the design and construction process. Major projects frequently take a number of years to complete, from the time that the original go-ahead decision is made. Construction engineering, right-of-way acquisition, and construction phases are not easily telescoped. Thus, the approval of a highway project is a decision that affects capital expenditures not only in the current year, but in subsequent years as well. Thus, in any given budget period, a certain portion of the total available funds may be allocated to projects whose approval decision has been made in past periods. The remaining amount after deducting the funds for these projects becomes the "effective" budget. Furthermore, in using the technique described in this paper, it will be necessary to recognize that the year's budgetary constraint does not apply to the total project cost, but only to that part of the cost that must be funded in the current year.

It may be appropriate to consider the budgetary constraint in terms of a longer period than a year. Highway revenues are generally predictable into the future with good precision, for they depend primarily on the relatively predictable amount of automobile travel. If revenues (and therefore, budgets) can be predicted two, three, or five years hence, and if sufficient project economic data are available to cover the maximum construction level over the same period, the more lengthy time frame has appeal. The reason is that the one-year budget level may, in some cases, just barely exclude a project, not because its cost of time is significantly higher than others selected, but because the total highway cost, when added to the cumulative highway costs of proposals previously chosen, would cause the single year budget to be exceeded. Analysis over a longer period would tend to introduce a "leveling" effect.

The Incremental Procedure

The most obvious procedure for selecting the set of proposals that will lead to the greatest average saving in time per budget dollar expended would be simply (a) to enumerate the total highway cost, user cost, and time savings for all possible sets of proposals, (b) to exclude those sets whose total highway expenditure exceeds the budget, and (c) to select the remaining set that has the greatest time savings. This procedure, though simple in concept, is likely to be very lengthy. In the example used in this paper, which has many fewer alternatives than many real situations, there are 400 possible sets of proposals. With a larger number of locations, the total number of possible sets becomes very large. It would be desirable to find a procedure that would ease this computational burden.

TABLE 4

PROJECTS CHOSEN USING INCREMENTAL COST OF TIME

Property	Value
Project identification	(1, 4), (2, 1), (3, 2), (4, 2)
Total increase in highway cost ($)	1,050,000
Total savings in user cost ($)	420,000
Total savings in travel time (hr)	1,860,000

The incremental analysis used in the previous section can be adapted to the cost of time solution. The procedure used is exactly the same, except that incremental costs of time are computed, instead of incremental benefit-cost ratios, and proposals are selected by the criterion of the smallest incremental cost of time.

The computations using the cost of time are again lengthy, and therefore the selection of an optimal set from the 14 hypothetical proposals is shown in detail in Appendix B.

For the cost of time procedure, the set of projects chosen is given in Table 4, along with the total change in highway cost, user cost, and time savings. The set chosen is the same as that chosen by the incremental benefit-cost ratio method using a value of time of $1.00 per hour.

The two procedures are compared in Table 5, in terms of their average cost of time. The set chosen using the cost of time procedure and the benefit-cost ratio procedure with V = $1.00 per hr provides significantly lower average cost of time than those selected using $1.50 per hr and $2.00 per hr in a benefit-cost ratio procedure.

The set derived using a willingness to pay of $1.50 per hr would result in greater time savings than the set chosen by the cost of time, but to attain these additional time savings, the incremental cost of time would be about $1.21 per hr. If this incremental cost of $1.21 could be justified on the basis of willingness to pay, then the $1.50 set should be accomplished. But it has already been admitted (in this example) that the value of time may be as low as $1.00 per hr; therefore, it is not possible to state with confidence that the willingness to pay is at least $1.21. If this is representative of the real situation, it is a good illustration of the fact that the willingness to pay cannot be completely ignored, and it also indicates the economic advantage of choosing projects by the cost of time procedure. (If some proposals were admitted whose cost of time was higher than the lowest estimated willingness to pay, then other factors than the cost of time savings would be necessary to justify these projects. Otherwise, it could be concluded that the budget may simply be larger than necessary for the number of available projects.)

TABLE 5

COMPARISON OF THE TWO PROCEDURES

Property	Cost of Time Procedure	Benefit-Cost Ratio Procedure		
		V = $1.00/Hr	V = $1.50/Hr	V = $2.00/Hr
Project Identification	(1, 4), (2, 1) (3, 2), (4, 2)	(1, 4), (2, 1) (3, 2), (4, 2)	(1, 2), (2, 2) (3, 2), (4, 2)	(1, 2), (2, 1) (3, 2), (4, 3)
Net change in dollar costs ($)	630,000	630,000	860,000	1,230,000
Change in travel time (hr)	1,860,000	1,860,000	2,050,000	2,220,000
Average cost of time ($/hr)	0.339	0.339	0.420	0.554

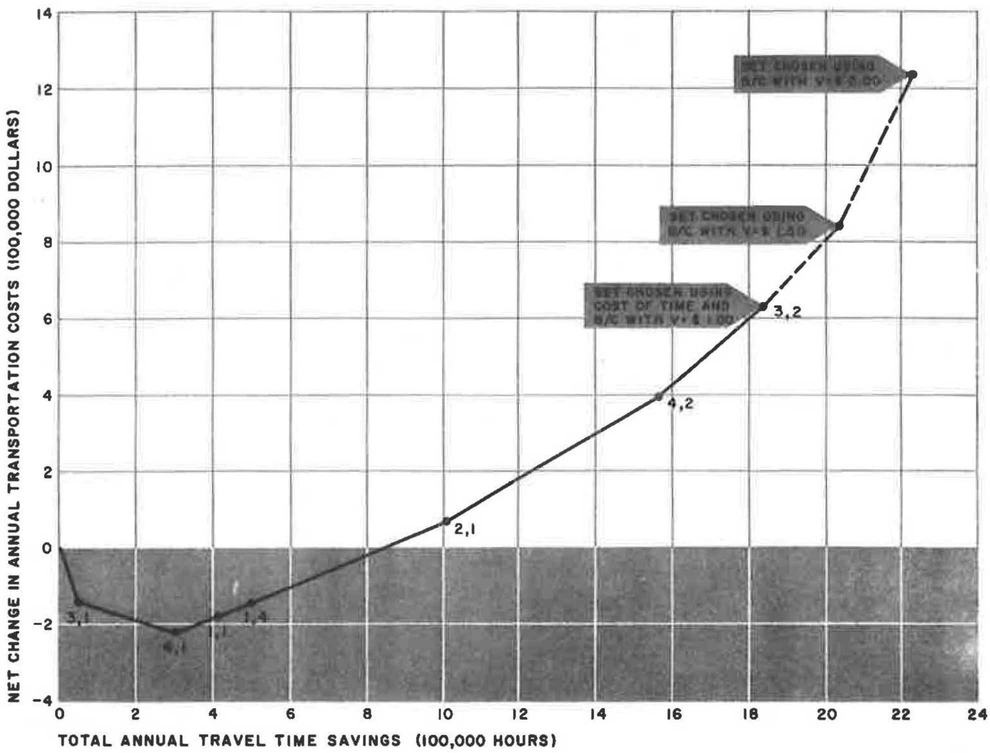

Figure 3. Comparison of the two procedures.

The set chosen using a willingness to pay value of \$2.00 per hr would have an incremental cost of time of \$2.18 per hr over the set chosen with V = \$1.50. Thus, using the incremental benefit-cost ratio procedure, it is possible to attain a final increment of time savings that is greater than the assumed willingness to pay value used in the calculations.

The results of the two methods are shown in Figure 3, which plots total highway-plus-user costs vs time savings. It also indicates the iterative steps taken in the cost of time procedure, with lines connecting the successive proposals chosen at each iteration — (3, 1) first, then (4, 1), (1, 1), etc. This illustrates the iterative procedure — that each proposal chosen is more costly (cost per hour saved) than the proposal chosen in the previous iteration.

USE OF COST OF TIME CONCEPT IN PRACTICE

The monetary worth of time is one of the most important factors, if not the most important factor, in determining the total user benefits of highway improvements. Therefore, if little confidence can be placed on an estimate of a willingness to pay, it is desirable that the analysis of proposals be carried out by considering the cost of time as a primary variable.

Up to this point in the paper, the discussion has centered around a somewhat theoretical development of a new procedure for economic analysis. This section considers the practical problems associated with the adoption of the procedure and suggests an alternative use of the cost of time concept.

The procedure might be used just as described by a governmental body administering highway improvement expenditures. So used, economic decisions involving design, location, and programing would be made simultaneously. (It is recognized that the programing function is very complex. In addition to economic considerations, programing must take into account the present status of construction projects, land acquisition, analysis of proposals in the design stages, the availability of contractors to perform the work, and other considerations that are not readily reduced to economic data. These considerations are important, so important that they frequently take precedence over the economic calculations. Nevertheless, this technique could improve the economic portion of the total programing process.)

However, to use the entire cost of time procedure as outlined would entail a substantial change in the methods of economic analysis now used by highway agencies. In addition, this procedure seems to throw time savings into an all-important position. Clearly, many highway projects are justified on bases other than time savings. Vehicle running cost savings and safety are but two of many other important reasons for constructing improved highways. For such reasons, the cost of time procedure as described does not answer all the questions that need to be raised about proposed highway projects.

What is really of interest is not a new procedure, but a value of time that can justifiably be used to convert time savings to dollar savings. The willingness to pay is such a figure, but another figure may prove equally useful in many cases in which economic analysis is used. This figure is the maximum allowable cost of time, as determined from a budget constraint.

It appears far more simple to estimate a maximum allowable cost of time than to estimate a willingness to pay. Determining a maximum allowable cost of time would entail analysis of past years' histories to aid future decisions. In this use it is recognized that funds available for highway purposes do not change radically from year to year (for example. fuel tax revenues remain relatively constant, and, in general, increase gradually and relatively evenly as automobile travel grows), aside from relatively infrequent changes in fuel tax rates.

To estimate a maximum allowable cost of time, it would be necessary to examine all alternative highway proposals that were considered within a budgetary period in the past (including the alternatives of design, location, and programing), together with the budgetary allocation associated with that specific group. The costs of time could be calculated as previously outlined and could be used to indicate how, on economic grounds alone, projects should have been chosen and expenditures should have been made. Almost certainly the set of optimal projects so derived will not agree with the set actually accomplished. This disagreement might be due, in part, to the use of the "wrong" value of time in the calculations, wrong in relation to the budgetary constraint. (A useful by-product of analysis of a number of budget-proposal sets would be a comparison of the different costs of time that result. For example, if analysis of improvements to Federal-aid primary highways indicated a cost of time significantly different from that resulting from analysis of Federal-aid secondary highways (and there were no significant differences between budget categories because of irreducible considerations), one could conclude that the two budgets analyzed were incorrectly established in relation to each other. Conversely, if it were decided that two areas should have different degrees of improvements (e.g., a tourist area and a commuter area), the extent to which this objective was attained could be evaluated. These comparisons might justify reappraisal of the budget-establishing process or provide further basis for using different values of time in different situations.)

In any event, the maximum incremental cost of time can be computed. This maximum cost of time would be the incremental cost for the last project selected by the iterative procedure. This is the value that could be considered for future economic analyses as a value of time. (With this method of solution, it may be that the final selection made is much more costly than the previous selection. This possibility could exist, if, when considering the last selection, many appealing alternatives are rejected because their selection would cause the total highway expenditure to exceed the budget, and it is still possible to select a poor improvement of low highway cost. In theory, the budget has been considered fixed and it has been assumed that as much of the budget will be expended as is possible. In practice, the budget amount is somewhat flexible, so that it may be a sufficiently practical rule to look no further once the next most attractive alternative would exceed the budget. The maximum allowable cost of

TABLE 6

EQUIVALENT ANNUAL TRANSPORTATION COST SAVINGS[1] WITH V = $0.822 PER HR

Location	Cost Savings ($)			
	Proposal 1	Proposal 2	Proposal 3	Proposal 4
1	60,200	24,800	84,000	95,800
2	194,600	191,400	-165,600	-308,200
3	201,200	201,200	-310,400	--
4	263,200	404,200	170,400	--

[1] Source: Stanford Research Institute.
[2] A negative cost of time indicates that increase in highway costs is less than savings in user costs.

time, for use in future evaluations, would be the cost for the project selected just prior to rejection of the first project for budget reasons. Vaswani (4) used the cost of time principle, in which the highway administrator would choose a maximum allowable cost of time on the basis of local "considerations," for a "reference" highway. In this paper, the cost of time would be computed from a budgetary constraint.)

In the example, the final proposal selected by the cost of time procedure (3, 2) has an incremental cost of time of just over $0.82. This final incremental cost is, for this budget and set of proposals, the maximum allowable cost of time, and can be used as a value of time to compute equivalent annual costs of all these 14 proposals. If this value is used, the set of projects chosen in the iterative cost of time procedure will have the greatest equivalent annual cost savings, as given in Table 6. Thus, the optimal set of projects could have been selected by computing equivalent annual costs with V = $0.82, and selecting those with the greatest savings. (Actually, at the location where the last selection is made (location 3), two proposals would have the same (most negative) equivalent annual costs (3, 1 and 3, 2) (Table 6). If among these two, the proposal is chosen with the greatest total time savings, the optimal set will be identified.) The same set would be selected by the incremental benefit-cost ratio approach with V = $0.82. This is the major conclusion of this paper: By use of a maximum allowable cost of time, the optimal set of projects would be automatically derived and the budgetary constraint would be nearly met by the sum of all the individual highway costs.

Thus, the maximum allowable cost of time is the correct value of time for those economic analyses concerned with evaluation of alternatives when the incoming revenue or budget must be treated as a fixed amount. The maximum allowable cost of time is appropriate when evaluating alternative designs or alternative locations; it is appropriate in programing analyses. In these analyses, it will provide (as much as possible within the discrete nature of highway proposals) equally costly time savings at all locations that fall within the particular budget.

On the other hand, the maximum allowable cost of time is not appropriate for economic analyses in connection with highway needs studies, or for any other analyses in which the objective of the analysis is to influence the setting of tax rates or the establishing of budget levels. In these cases, the maximum willingness to pay is the appropriate conversion figure, for it is the standard of comparison which reflects highway users' desires.

But until a maximum willingness to pay value of time can be estimated with accuracy, no method of economic calculation can accurately influence the tax rate and budget allocation process, and no method of calculation can justify a project on absolute grounds.

CONCLUSIONS

A maximum willingness value of time is commonly used in economic analyses to convert travel time savings in hours to dollar values. However, little confidence can be placed on the results of these analyses, because little is known about the actual willingness to pay. It is demonstrated in this paper that the projects selected are dependent on the value of time chosen, and that, if the actual willingness to pay value differs much from the chosen value, the projects selected may not be the most desirable projects.

The cost of time procedure presented in this paper allows projects to be selected within a budget constraint without dependence on an estimated willingness to pay, which may be inaccurate. When time savings play an important part in the total benefits associated with an improvement proposal, it is appropriate to direct attention in their direction by computing the cost of time.

The most immediately practical use of the cost of time procedure would be to estimate the maximum allowable cost of time, using data on the past year's proposals and past year's budgets. This cost of time could then be used as a value of time to evaluate alternatives of design or of location and to formulate highway programs. In this way, time savings over the entire highway district will be attained at minimum cost.

ACKNOWLEDGMENTS

This paper is one result of a preliminary study of the theory and principles involved in measuring the value of time to the occupants of passenger cars. The study was sponsored by the Bureau of Public Roads.

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Appendix A

SELECTION OF PROPOSALS USING INCREMENTAL BENEFIT-COST RATIOS

This appendix describes the detailed procedure of the use of benefit-cost ratios to select a set of highway improvement proposals. The data presented in the main body of the paper on hypothetical proposals at four locations are used as an example to display the numerical calculations involved. The computation is shown for an assumed willingness to pay value of $1.00 per hr. The procedure for other values is the same.

The first step is to order the alternatives in terms of increasing highway cost and compute the incremental benefit-cost ratios for all alternatives over all other alternatives at each location separately. At location one, the incremental ratios are computed for

(1, 1), (1, 2), (1, 3) and (1, 4) vs (1, 0)[1]
(1, 2), (1, 3) and (1, 4) vs (1, 1)
(1, 3) and (1, 4) vs (1, 2)
(1, 4) vs (1, 3)

Proposal (1, 1) compared with (1, 0) has an annual highway cost of $20,000, a savings in user costs of -$10,000 and a savings in travel time of +110,000 hr. The incremental

[1] The "do nothing" or existing situation is indicated as (1, 0).

TABLE 7

COMPUTATION OF INCREMENTAL BENEFIT-COST RATIOS

Location 1

Vs ↙	1,1	1,2	1,3	1,4
1,0	5.0	1.71	1.80	1.57
1,1		0.40	1.31	1.24
1,2			1.88	1.50
1,3				1.13

Location 2

Vs ↙	2,1	2,2	2,3	2,4
2,0	2.12	1.70	1.00	0.89
2,1		1.19	0.58	0.55
2,2			0.31	0.37
2,3				0.48

Location 3

Vs ↙	3,1	3,2	3,3
3,0	2.00	1.74	1.00
3,1		1.36	0.49
3,2			0.04

Location 4

Vs ↙	4,1	4,2	4,3
4,0	3.82	3.62	2.03
4,1		3.40	1.30
4,2			0.06

TABLE 8

ITERATIVE STEPS USING INCREMENTAL BENEFIT-COST RATIOS WITH A BUDGET CONSTRAINT OF $1,100,000 FOR V = $1.00 PER HR[a]

Itera-tion	Proposals Compared Against	Selection		Cumulative Highway Cost ($)
		Proposal	B-C Ratio	
1	(1, 0), (2, 0), (3, 0), (4, 0)	(1, 1)	5.0	20,000
2	(1, 1), (2, 0), (3, 0), (4, 0)	(4, 1)	3.82	130,000
3	(1, 1), (2, 0), (3, 0), (4, 1)	(4, 2)	3.40	230,000
4	(1, 1), (2, 0), (3, 0), (4, 2)	(2, 1)	2.12	490,000
5	(1, 1), (2, 1), (3, 0), (4, 2)	(3, 1)	2.00	700,000
6	(1, 1), (2, 1), (3, 1), (4, 2)	(3, 2)	1.36	840,000
7	(1, 1), (2, 1), (3, 2), (4, 2)	(1, 3)	1.31	970,000
8	(1, 3), (2, 1), (3, 2), (4, 2)	(2, 2)	1.19	1,180,000[b]
9	(1, 3), (2, 1), (3, 2), (4, 2)	(1, 4)	1.13	1,050,000

[a] No further available alternatives have benefit-cost ratios greater than 1.0; therefore, final set is composed of last project selected at each of four locations; that is, projects (1, 4), (2, 1), (3, 2), and (4, 2).

[b] Exceeds budget.

benefit-cost ratio, using a willingness to pay of $1.00 per hr, is [(1.00) (110,000) + (-10,000)]/ 20,000 = 5.00. For proposal (1, 2) compared with (1, 1) the incremental benefit-cost ratio is [(1.00) (140,000 - 110,000) + (-20,000 + 10,000)]/(70,000 - 20,000) = 0.40. Table 7 gives the incremental benefit-cost ratios for all alternatives at the four locations.

The nine iterative steps required to make the selection of projects are given in Table 8. Following the iterative procedure described in the main body of the paper, in the first iteration, all 14 proposals are compared with their "do nothing" alternative [indicated in the second column as (1, 0), (2, 0), (3, 0), (4, 0)]. Following across the first line in all four tabulations in Table 7 shows that the greatest benefit-cost ratio is for proposal (1, 1) vs (1, 0). The benefit-cost ratio is 5.0 and the highway cost is $20,000, which is entered as the first iteration in Table 8.

In the second iteration, proposals (1, 2), (1, 3), and (1, 4) are compared against (1, 1), and all other proposals are compared against the "do nothing" condition. Thus, in the second column, proposals (1, 1), (2, 0), (3, 0), and (4, 0) are listed. In this iteration, proposal (4, 1) is most attractive, with a benefit-cost ratio of 3.82, as indicated in Table 8.

In the eighth iteration, proposal (2, 2) is most attractive, but adding this to the cumulative highway expenditure to that step would exceed the budget of $1,100,000.

Th iterative procedure continues until no further projects can be selected which will not exceed the budget, or until no further alternatives have benefit-cost ratios greater than 1.0.

Appendix B

SELECTION OF PROPOSALS USING INCREMENTAL COST OF TIME

This appendix describes the detailed procedure of the use of a cost of time concept to select an optimal set of highway improvement proposals. The data presented in the main body of the paper on hypothetical proposals at four locations are used as an example to display the numerical calculations that are involved.

The first step is to order the alternatives in terms of increasing highway cost and compute the incremental costs of time for all alternatives over all other alternatives at each location separately. At location one, the incremental costs are computed for

(1, 1), (1, 2), (1, 3) and (1, 4) vs (1, 0)[2]
(1, 2), (1, 3) and (1, 4) vs (1, 1)
(1, 3) and (1, 4) vs (1, 2)
(1, 4) vs (1, 3)

Proposal (1, 1) compared with (1, 0) has an annual highway cost of $20,000, a savings in user costs of -$10,000 and a savings in travel time of +110,000 hr. The incremental cost of time is [($20,000) - (-$10,000)]/+ 110,000 = $0.27 per hr. For proposal (1, 2) compared with (1, 1) the incremental cost of time is [($70,000 - $20,000) + ($20,000 - $10,000)]/(140,000 - 110,000) = $2.00 per hr. Table 9 gives the incremental costs for all alternatives at the four locations.

The seven iterative steps are given in Table 10. The iterative procedure is described in the main body of the paper. In the first iteration, all 14 proposals are compared with their "do nothing" alternative. Project (3, 1) presents the most attractive investment with a cost of -$3.20 per hr over (3, 0). The negative cost of time indicates that both total dollar costs and travel time would be reduced. Its capital cost is $210,000, which is less than the $1,100,000 equivalent annual budget, and it is selected for completion.

In the second iteration, proposals at locations 1, 2, and 4 are compared with their

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[2]The "do nothing" or existing situation is indicated as (1, 0).

TABLE 9

COMPUTATION OF INCREMENTAL COSTS OF TIME (Dollars per Hour)

Location 1

Vs ↙	1,1	1,2	1,3	1,4
1,0	0.27	0.64	0.40	0.32
1,1		2.00	.56	.38
1,2			-.17	-.60
1,3				2.00

Location 2

Vs ↙	2,1	2,2	2,3	2,4
2,0	.45	.57	1.00	1.13
2,1		.83	1.74	1.91
2,2			3.20	3.09
2,3				2.86

Location 3

Vs ↙	3,1	3,2	3,3
3,0	-3.20	.21	1.00
3,1		.82	1.38
3,2			1.93

Location 4

Vs ↙	4,1	4,2	4,3
4,0	-.19	.32	.68
4,1		.56	.92
4,2			1.39

TABLE 10

ITERATIVE STEPS USING INCREMENTAL COST OF TIME WITH A BUDGET CONSTRAINT OF $1,100,000[a]

Itera-tion	Proposals Compared Against	Selection		Cumulative Highway Cost ($)
		Proposal	Cost of Time	
1	(1, 0), (2, 0), (3, 0), (4, 0)	(3, 1)	-3.20	210,000
2	(1, 0), (2, 0), (3, 1), (4, 0)	(4, 1)	-0.19	320,000
3	(1, 0), (2, 0), (3, 1), (4, 1)	(1, 1)	0.27	340,000
4	(1, 1), (2, 0), (3, 1), (4, 1)	(1, 4)	0.38	550,000
5	(1, 4), (2, 0), (3, 1), (4, 1)	(2, 1)	0.45	810,000
6	(1, 4), (2, 1), (3, 1), (4, 1)	(4, 2)	0.56	910,000
7	(1, 4), (2, 1), (3, 1), (4, 2)	(3, 2)	0.82	1,050,000

[a] No further alternatives can be selected to keep cumulative highway cost less than budget; therefore, final set is composed of last project selected at each of four locations; that is, projects (1, 4), (2, 1), (3, 2), and (4, 2).

"do nothing" condition, and proposals (3, 2) and (3, 3) are compared with (3, 1). In this iteration, proposal (4, 1) is the most attractive and the highway cost of (3, 1) plus (4, 1) does not exceed the budget.

In the seventh iteration, proposal (3, 2) is chosen. No further improvements are possible without exceeding the budget.

Effect of Highway Improvement on Travel Time of Commercial Vehicles

A Twenty-Five-Year Case Study

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The time saved by both private and commercial vehicles as the result of expenditures for highway construction, improvement, and maintenance is clearly of considerable importance to those engaged in evaluating prospective consequences of investment decisions. Studies of actual economic analyses indicate that decisions are frequently quite sensitive to the way in which analysts treat the value of time.

In essence, there are two aspects to the "time problem": (a) the numerical dollar value placed on units of time savings, and (b) the method of introducing the savings in the analysis. The subject of this paper applies principally to the latter; it is essentially a case study, examining in detail the interrelationships of two major sections of highway and a principal commercial user over a 25-yr period. Evidence developed clearly indicates that time is not economically significant simply when it is "released" by highway improvement; there is a considerable lag between the point at which time is saved and that at which it can be utilized in an economic sense. If conditions represented by the study are at all representative of conditions elsewhere in the country, then it follows that present methodology is incorrect in that it fails to give proper effect to the timing of this important consequence of highway improvement.

•FOR MANY YEARS in the United States, expenditure of public funds for highway construction, improvement, and maintenance has resulted largely from the subjective judgments of certain elected or appointed public officials. Choosing among possible investment alternatives has in general been guided by the principle of "the squeaky wheel gets the grease" or by so-called "sufficiency rating" techniques. Only isolated instances of application of sound objective methodology have been evident until the early 1950's.

Despite the type of criterion used to select among proposals (benefit-cost ratio, rate of return, excess of benefits over costs, etc.), all methods require measurement of the beneficial and adverse consequences of a particular investment alternative. Furthermore, all analysts agree that the time saved by vehicles, both private and commercial, is relevant to any highway economy study. This paper deals with the economic value of time saved by commercial vehicles as a result of highway investment in the context of quantitative history of a long section of highway over a large number of years in conjunction with the activities of a major user of that highway over the same period. It is the author's observation that such a "macro-view" has rarely been presented before—at least in available literature.

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Two stretches of highway have been selected for study: US Interstate 5 between Portland and Grants Pass, Ore. (sometimes called the Pacific Highway or US 99), and US Interstate 5 between Portland and Seattle, Wash. In 1960, the route length of the former was 248 mi and that of the latter was 162 mi. The primary reasons for selection of these two sections of highway are (a) the common carrier of interest has used them over many years, and (b) cost and other data are comparatively readily available. Moreover, the operating schedules of the carrier are such that the cities of Grants Pass, Portland, and Seattle are of particular interest.

Consolidated Freightways, Inc., the largest trucking common carrier in the United States, was selected as the carrier of interest primarily because it has continuously used these routes for many years. Moreover, the company's activities over these highways were believed typical of over-the-road operation in other parts of the country.

The original plan was to examine the interrelationship between the highway and the commercial user for a period of 25 years, 1935-60. Although this objective was accomplished in most instances, data of interest are not complete for that entire period. Every effort has been made, however, to include all usable historical data covering as long a time span as possible between the years 1935 and 1960.

THE PROBLEM

Present Techniques of Treating Commercial Vehicle Time

Although there presently exists considerable controversy as to the appropriate numerical value to be assigned to time savings of commercial vehicles, there is general agreement as to the assumptions underlying the methodology involved in evaluating this time. The purpose of this section is to enumerate and discuss briefly certain common aspects of present techniques.

To consider a simplified but typical example, a project is being evaluated which is designed to save on completion of construction 10 sec per commercial vehicle; traffic studies indicate an average daily traffic (ADT) of 2,000 commercial vehicles in the first year. Then the total commercial vehicle-hours saved in the first year is ordinarily computed to be 10 sec per veh × 2,000 veh per day × 365 days per yr × 1 hr per 3,600 sec, or 2,028 hr. Assuming that this is a 30-year project and that year + 15 will be selected as the base year for purposes of analysis, then, if traffic estimates indicate that ADT in year + 15 will be 150 percent of year + 1, the commercial vehicle time saved in the base year is 1.50 × 2,028, or 3,042 hr. Finally, assuming that the present average hourly straight-time wage rate of commercial vehicle drivers in the geographic area of interest is estimated to be $3.00, then the total average annual value of commercial vehicle time saved is thus assumed to be $3.00 × 3,042, or $9,126. In most studies this sum is interpreted as the equivalent uniform annual benefit attributable to the project resulting from savings in commercial vehicle time.

There are, of course, a number of minor variations to the methodology illustrated by the example. For instance, a different "time cost" per hour may be applied to various classes of commercial vehicles, or the analyst may assume more than one occupant per vehicle. Nevertheless, the procedure just outlined is the one presently in vogue among analysts making highway economy studies in the United States, and occasional minor variations do not negate the general assumptions underlying the methodology.

The first of these assumptions is that time saved has economic value immediately on realization. That is, owners of the affected vehicles are able to make economic use of time saved as soon as it is "released" by highway improvement.

Second, additivity of increments of time is assumed. In the example, the 3,042 hr per yr saved resulted from the addition of many 10-sec increments. It is clear that, if the sum of increments has a given value, each of the individual increments has a proportional part of that value.

Third, it is frequently assumed that total hours of time saved are valued at the average straight-time wage rate of drivers in the geographic area of the highway improvement, although this may be changed due to the results of the Highway Cost Allocation Study (20).

Use of a "base year" concept rather than computations based on gradient growth is a fourth assumption underlying present methodology. That is, the value at the base year is selected as representative of all years, and is interpreted as equivalent to the uniform annual benefit.

Fifth, generally no provision is made for wage inflation. Because only the differences between alternatives are relevant, this omission may be unimportant if all cost elements vary at the same rate or exist in the same proportion in each alternative.

"Additivity of Increments" Argument

Inherent in current methodology is the assumption that small increments of time are additive. For instance, the example assumed that many 10-sec increments of realized time savings could be added together to produce a gross value for number of hours saved during the year.

Several arguments can be used to justify this assumption. First, it is clear that vehicles are not necessarily affected by improvement or construction of a single project but rather the sum of improvements over long sections of highway. That is, if a vehicle traverses 20 mi of highway, and if there are twenty such "10-sec improvements" over those 20 mi, then the time saved is a much larger figure—200 sec.

A second argument advanced in support of the additivity assumption is that these improvements not only affect large sections of highway but also take place over long periods of time. Even the most naive driver should be aware of substantial changes in the highway system in his area over a period of, say, the past five years. In view of these two preceding arguments, it is asserted that, though extremely short time increments may have little or no economic value in themselves, value does result from considering the accumulation of many such incremental improvements over long periods of time and long sections of highway.

A third facet of this assumption is the question of immediate economic usefulness of time saved by vehicles. If, as it has just been argued, the only reasonable way of apportioning savings resulting over the long run is to assign them to individual increments, then it follows that the highway user must be able to take immediate economic advantage of each increment. If this is not true, then some increments are relatively more valuable than others.

Despite general acceptance of the "additivity of increments" argument, there are a number of powerful objections. The first of these asserts that there is a time lapse (between the time at which an improvement is made and the point when drivers take advantage of the improvements) due to driving habits. That is, individual drivers may be used to a certain pattern of behavior on a given highway or highway system and will not readily abandon this pattern until some time after the improvement has been made. An example of such behavior is insistance on driving at a certain speed level below the maximum speed allowed by either law or road and traffic conditions.

A second objection is that operating characteristics of the carrier employing the commercial vehicle prevent full utilization of time saved. For example, a truck is transporting goods between cities A and B. If the truck has been arriving at its destination at 4:00 AM but, after improvement of the highway, is now able to arrive at 3:50 AM, then in this case it is unlikely that the ten minutes saved have any economic significance at all, particularly if the earlier arrival of the freight is of little benefit to the dock personnel at the destination terminal.

Finally, restrictions imposed by labor union contracts often mitigate or negate any savings in time accruing to the commercial vehicle as a result of highway improvement. A classic example of this situation is the eight-hour guaranteed wage which exists almost everywhere in the United States. Under these conditions a driver is guaranteed a full eight hours pay even though he may work only for some shorter period. A typical case is a driver who travels from A to B in, say, seven and one-half hours. Should the highway be improved to the point where he can make the trip in seven hours, or even six hours, the cost to his employer remains the same because a full eight hours of wages must be paid. (It should be noted that this simple example implies that the driver cannot be utilized at either the origin or destination terminals;

e. g., handling freight. This may not always be the case, although union contracts in the eleven Western States generally prohibit drivers from handling the freight at terminals or otherwise engaging in activities not directly related to the driving function.) On the other hand, of course, a reduction in trip time from, say, nine to eight hours results in a savings of one hour of overtime. Estimation of the economic consequences of highway improvements requires knowledge of the effects of the improvements on operations of the carriers.

Referring to the preceding discussion of the "additivity of increments" argument, it is clear that there are reasonable arguments opposing such assumptions. Unfortunately, however, these arguments remain in the realm of theory until researchers offer evidence either substantiating or refuting them. It is the purpose of this paper to report the results of an investigation designed to examine the validity of these assumptions which are currently so widely held and which are so important in the area of highway economics. Moreover, in exploring this topic a number of other questions of interest to highway analysts have been examined. These include (a) what changes the highway has undergone over a long period of time; (b) how the character of operations of the carrier has changed over this same period; (c) what the relationship, if any, is between expenditures in construction-improvement-maintenance of a highway and the travel time between points on the highway; (d) what changes have been made in wages, hours, and working conditions of drivers; and (e) whether the straight-time driver wage is a proper measure of the economic value to the carrier of time saved.

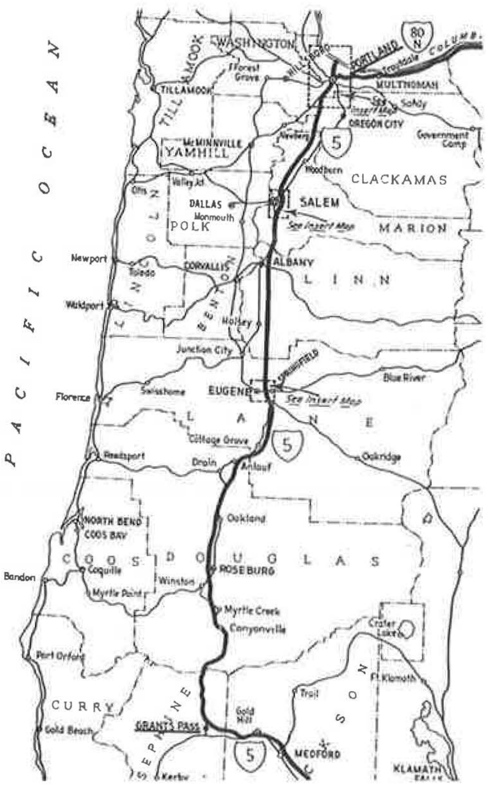

Figure 1. Truck route between Portland-Grants Pass.

THE HIGHWAY

During the data-gathering phase of the study, an attempt was made to get the same kind of information in similar form from both the Oregon and Washington State Highway Departments. The categories of data collected for the years 1935-60 are as follows:

1. Description of highway.
2. Annual construction, improvement, and maintenance costs.
3. Length of route.
4. Average daily traffic.
5. Traffic composition.
6. Traffic speed.

Although most of these data were provided by the Highway Departments of both States, the form in which it was received was dissimilar in some instances; hence, the minor variations between Oregon and Washington data.

Highway Between Portland and Grants Pass, Ore.

During the years 1935 through 1960, Consolidated Freightways' trucks operated over the highway between Portland, in the northwest corner of Ore., and Grants Pass, about 250 mi south of Portland. The subject highway is shown as Interstate Route 5 (Fig. 1).

TABLE 1

CONSTRUCTION, IMPROVEMENT AND MAINTENANCE COSTS[1], PORTLAND TO GRANTS PASS[2]

Year	Construction and Improvement Costs ($)		Maintenance Cost ($)
	Affecting Traffic	Aesthetic Value Only	
Before 1935	18,215,177	-	1,903,367
1935	757,359	-	156,470
1936	488,346	27,417	121,387
1937	1,441,770	-	162,792
1938	2,008,132	7,063	155,755
1939	371,447	7,529	153,204
1940	739,649	12,819	174,188
1941	1,117,492	2,243	192,504
1942	415,227	39,617	179,457
1943	1,157,546	-	234,639
1944	386,370	-	219,845
1945	340,436	-	259,143
1946	598,098	-	321,217
1947	1,614,419	1,316	458,066
1948	1,834,583	-	477,946
1949	2,475,727	-	628,986
1950	1,282,535	17,238	572,175
1951	1,364,410	28,756	643,784
1952	4,659,012	3,041	727,611
1953	2,479,429	11,534	697,036
1954	1,616 355	10,788	711,965
1955	11,808,501	44,262	632,400
1956	11,927,062	97,518	735,586
1957	6,544,464	139,766	801,640
1958	24,367,026	204,741	1,509,382
1959	18,396,291	87,531	831,949
1960	22,428,581	26,117	634,660

[1] Data provided by Oregon State Highway Department.

[2] Intersection of Union Avenue and Burnside Street in Portland to north end of Caveman Bridge in Grants Pass (1958 through 1960 begin on Harbor Drive at undercrossing of Burnside St.).

Construction, Improvement, and Maintenance Costs. —Because it is the partial purpose of this paper to indicate the relationship between highway expenditures and improved operations of the user, it was necessary to separate construction and improvement costs into two categories: those affecting traffic and those of aesthetic value only. The latter includes such items as planting of grass and shrubbery along the roadside and any other similar improvements which have no direct effect on vehicle speed. These appear with regard to construction and improvement costs, but are not relevant to maintenance expenditures.

Construction, improvement, and maintenance costs as reported by the Oregon State Highway Department are given in Table 1. Two observations can be made immediately from these raw data: (a) it is evident that total expenditures on the highway range widely from year to year; and (b) extremely large expenditures were experienced for the years 1955 through 1960. It was during this period that major construction was undertaken with the objective of bringing the highway into the Federal Interstate System.

Although the data in Table 1 are helpful, it is somewhat more illuminating to modify the statistics slightly. Due to variations in construction prices during the 26-year period, all annual construction, improvement, and maintenance costs were adjusted by appropriate values from the construction index as prepared by the Oregon State Highway Department. The adjusted data for construction and improvement were then added cumulatively, ignoring those expenditures that were of aesthetic value only. Results of this data modification are shown in Figure 2. The accelerated improvement program beginning in the early 1950's is clearly evident as is the attendant increase in maintenance costs.

Point-to-Point Mileage. —Detailed year-by-year route descriptions provided by the Oregon State Highway Department (not included in this paper) clearly indicate a number of alterations in highway alignment during the 1936-60 period. A major purpose of these changes, of course, was to bypass populated communities and otherwise shorten the travel time of vehicles passing through.

The reduction in highway distance traversed by Consolidated Freightways' trucks in traveling between Portland and Grants Pass is evident from Table 2 and Figure 3. Route distance was reduced by 30.55 mi during the 1935-60 period, an 11 percent overall improvement. The reduction is even more pronounced when one considers that the straight-line distance between Portland and Grants Pass is approximately 212 mi. Thus, in 1935 the route was about 67 mi above the theoretical minimum distance, and this "excess distance" was roughly 37 mi by 1960. The improvements, therefore, represent a reduction in the order of 45 percent of the greatest conceivable reduction. Referring to Figure 1, it is apparent that the locations of population and market centers between Portland and Grants Pass preclude the construction of a straight-line route between the two cities. Such a highway, at least in the foreseeable future, would be an improbable luxury. Hence, it is reasonable to assume that nearly all of the practicable reduction in distance has already taken place.

Average Daily Traffic. —Some indication of increase in use of the highway between 1935 and 1960 can be provided by statistics showing the ADT.

The Oregon State Highway Department conducts traffic counts at a number of points between Grants Pass and Portland. Of these, three have been chosen because of their strategic location:

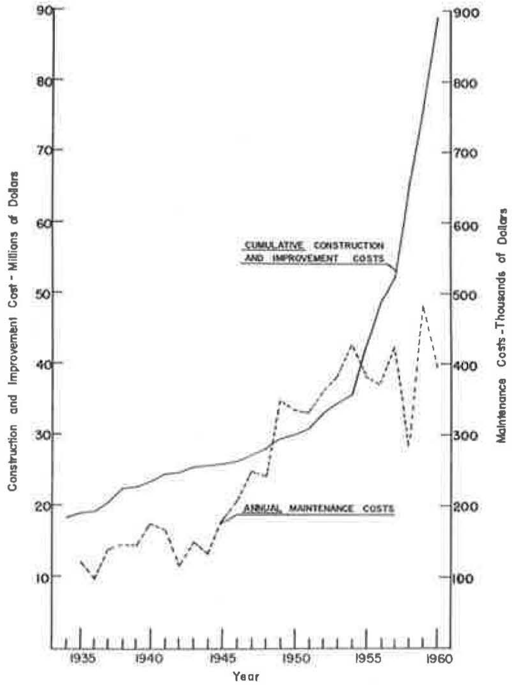

Figure 2. Construction, improvement and maintenance costs, Portland to Grants Pass adjusted by Oregon construction cost index (1940=100) except for years before 1935.

TABLE 2

LENGTH OF ROUTE[1], PORTLAND TO GRANTS PASS[2]

Year	Length of Route (mi)
1935	279.13
1936	279.13
1937	277.40
1938	276.70
1939	276.70
1940	275.92
1941	275.00
1942	275.08
1943	275.08
1944	272.26
1945	272.26
1946	272.26
1947	270.37
1948	269.02
1949	269.02
1950	269.02
1951	269.22
1952	268.75
1953	268.75
1954	268.75
1955	259.91
1956	260.02
1957	254.95
1958	253.52
1959	253.52
1960	248.58

[1] Data furnished by Oregon State Highway Department.

[2] Intersection of Union Avenue and Burnside Street in Portland to north end of Caveman Bridge in Grants Pass.

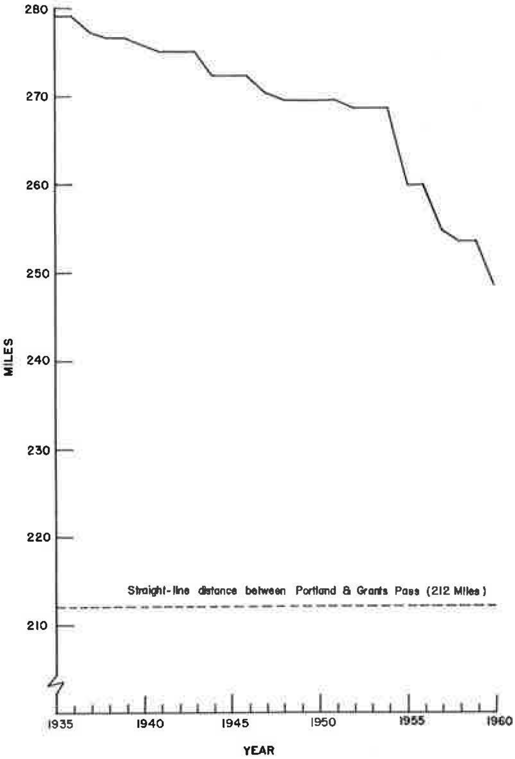

Figure 3. Length of route used by Consolidated Freightways' trucks, Portland to Grants Pass.

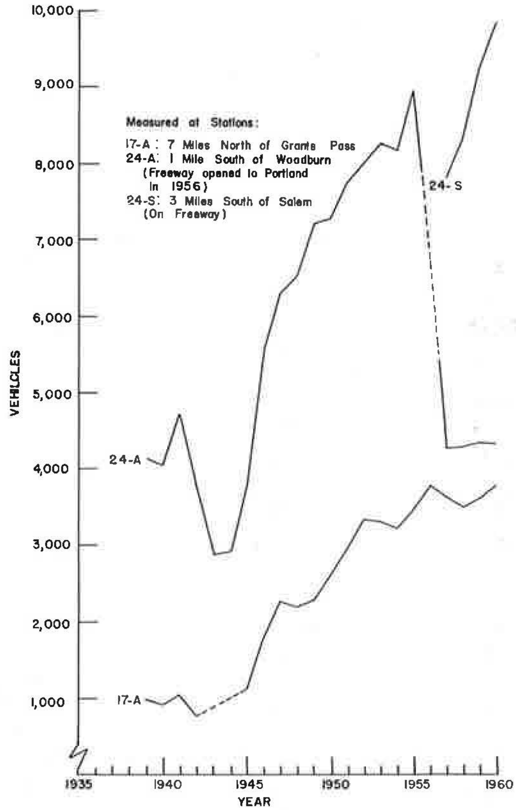

Figure 4. Average daily traffic, Portland to Grants Pass.

1. Station 17-A, 7 mi north of Grants Pass,
2. Station 24-A, 1 mi sourth of Woodburn, and
3. Station 24-S, 3 mi north of Salem.

Station 17-A was selected because the highway at that point has remained essentially unchanged during the past 25 years. That is, there have been no major highway system changes in that area which might have seriously altered the pattern of traffic flow.

Stations 24-A and 24-S should be considered together to appreciate changes in highway usage. The first of these is located on that portion of the highway which was the main route prior to opening of the Pacific Freeway in November 1956. Station 24-S is located on the new Pacific Freeway and hence measures traffic flow on the current principal through route.

ADT statistics are given in Table 3 and Figure 4. It is clear that, with the exception of the World War II period, traffic usage has been steadily increasing. In noting Station 17-A (just north of Grants Pass), it appears as though the rapid growth of the postwar era has begun to taper off. Stations 24-A and 24-S, on the other hand, indicate that rate of growth is continuing unabated. These differences may be explained in part by the urban character of the area between Salem and Portland; it is reasonable to expect that opening of a freeway in that area would attract a great deal of local traffic. Moreover, the reduction in through traffic on the old highway (measured at Station 24-A), with the resulting decrease in congestion, has probably caused the diversion of local traffic that previously had avoided the route. That is, Stations 24-A and 24-S doubtless measure traffic diverted from other local roads in addition to normal growth and transfers from the old highway (24-A) to the new one (24-S).

TABLE 3

AVERAGE DAILY TRAFFIC[1], PORTLAND TO GRANTS PASS

Year	Average Daily Traffic			
	Station 17-A	Station 24-A	Station 24-S	Stations 24-A and 24-S Combined
1939	991	4,135	-	-
1940	915	4,054	-	-
1941	1,053	4,729	-	-
1942	769	3,736	-	-
1943	No data	2,881	-	-
1944	No data	2,914	-	-
1945	1,111	3,760	-	-
1946	1,783	5,577	-	-
1947	2,257	6,314	-	-
1948	2,180	6,533	-	-
1949	2,272	7,219	-	-
1950	2,624	7,273	-	-
1951	2,977	7,759	-	-
1952	3,327	8,008	-	-
1953	3,307	8,301	-	-
1954	3,209	8,201	-	-
1955	3,462	8,974	-	-
1956[2]	3,784	6,716	-	-
1957	3,636	4,260	7,806	12,066
1958	3,491	4,277	8,318	12,595
1959	3,594	4,354	9,273	13,627
1960	3,779	4,329	9,856	14,185

[1] Data provided by Oregon State Highway Department.
[2] Pacific Freeway opened to Portland in November.

Traffic Composition.—Table 4 gives the distribution of traffic on the route used by Consolidated Freightways' trucks as measured at the three locations discussed in the preceding section. The data will not be analyzed other than to point out that (a) there has been no apparent trend or shift in traffic composition over the past 22 years, and (b) the percentage distributions noted north of Grants Pass are quite similar to those observed in the Salem-Woodburn area.

Traffic Speed.—The large and increasing expenditures made for construction, improvement, and maintenance of the highway during the 1935-60 period was demonstrated earlier. The rapid increase of highway usage during the same period has also been shown. Despite the greater number of vehicles on the highway, studies indicate that expenditures have generally resulted in an increase in overall traffic speed.

The magnitude of these increases is given in Table 5. Although vehicle speed data are collected at a number of measurement stations, the following three locations were selected for this discussion:

1. Station 24-1, Pacific Highway East, 5 mi south of Woodburn,
2. Station 24-2, Interstate 5, north of Salem, and
3. Station 24-3, Pacific Highway, 10 mi south of Salem.

Station 24-1, located just south of Woodburn, has remained essentially unchanged during the period 1949-60. The highway in the area is not built to freeway standards. Station 24-2, on the other hand, is located on the freeway section of Interstate 5 north of Salem, and data are available at this point for years 1956-60. The third data collection point, Station 24-3, is located south of Salem on a section of the highway which was improved to freeway standards in 1959.

The data of Station 24-1 are perhaps the most revealing because they supplement the freeway data recorded at Station 24-2. As noted earlier, traffic formerly moving on Pacific Highway East has been diverted to Interstate Route 5 in the area between Salem and Woodburn because of the construction of the latter to freeway standards. One would intuitively reason that such a diversion would occur, not only because of increased comfort and convenience on the new highway, but also because of opportunity for increased speed. However, not only were vehicles using the new highway able to travel at higher speeds than formerly, but those users remaining on the old route were able to do likewise. This phenomenon is probably caused by reduction in traffic congestion on the old road, allowing an increase in average speed. (Fig. 4 shows changes in traffic density on the opening of the new highway.)

Traffic speed is a function of vehicle capabilities and legal speed limits, in addition to highway characteristics. The truck speed limits in Oregon since 1935 are as follows:

Period	Speed (mph)	
	Minimum	Maximum
1935 - June 1941	None	35
June 1941 - July 1957	None	45
July 1957 to date	None	50

There was a wartime speed restriction on all vehicles of 35 mph between October 1948 and September 1945.

In view of the legal limits on truck speed, it is interesting that average commercial vehicle speeds as recorded at the measuring stations have frequently exceeded the legal maximums. For example, of the eleven statistics reported at Station 24-3, six of these are "violations." That is, the reported average speeds are in excess of maximum legal speeds for the respective years. Moreover, commercial vehicles operating on the two freeway routes, Stations 24-2 and 24-3, have apparently reached the maximum legal speed. Future readings of about 50 mph are therefore to be expected unless there is an increase in the speed limit.

Highway Between Portland, Ore., and Seattle, Wash.

Consolidated Freightways' trucks have operated between Portland and Seattle for over thirty years. Portland is in the northern part of Oregon, just a few miles south of the Oregon-Washington State Line, and data concerning this highway, therefore, had to be furnished by the Highway Departments of both States. The present truck route between Seattle and the Oregon State Line is shown as Interstate Route 5 in Figure 5.

Construction, Improvement, and Maintenance Costs.—As was the case for the section between Portland and Grants Pass, the 1935-60 period witnessed steady, ever-increasing costs of construction, improvement, and maintenance on the Portland-Seattle highway. Actual costs as provided by the Oregon and Washington Highway Departments are shown in Table 6.

Cost data for the Portland-Seattle highway have been adjusted by Construction Cost Indexes. The adjusted figures for construction and improvement were then added cumulatively, ignoring those expenditures that were of aesthetic value only, and are shown in Figure 6 along with annual maintenance costs. As was the case with the Portland-Grants Pass highway, Figure 6 clearly shows the impetus given the construction and improvement program beginning about 1950.

Although annual maintenance costs have increased since World War II, they have

TABLE 4

PERCENTAGE OF AVERAGE DAILY TRAFFIC[1], PORTLAND TO GRANTS PASS

Station	Year	Average Daily Traffic (%)						
		Light Vehicles[2]	Light Trucks[3]	Heavy Trucks[4]	Truck & Semi-Trailer	Truck & Full Trailer	Total Trucks (except light trucks)	Buses
17-A	1939	83.5	5.2	9.4			9.4	1.9
	1940	84.0	4.9	9.1			9.1	2.0
	1941	84.5	6.0	3.0	2.4	2.6	8.0	1.5
	1942	81.7	5.3	3.6	2.9	4.3	10.8	2.2
	1943			No classification counts				
	1944			No classification counts				
	1945	80.0	5.4	3.3	3.0	6.1	12.4	2.2
	1946	84.5	4.9	3.8	2.1	2.8	8.7	1.9
	1947	83.0	5.2	4.7	2.9	2.5	10.1	1.7
	1948	80.7	7.3	4.0	3.4	3.1	10.5	1.5
	1949	80.3	7.4	3.6	3.7	3.4	10.7	1.6
	1950	79.1	8.4	3.3	3.4	4.3	11.0	1.5
	1951	87.5	1.0	3.2	2.6	4.8	10.6	0.9
	1952	88.1	1.0	4.0	4.6	1.5	10.1	0.8
	1953			No classification counts				
	1954			No classification counts				
	1955	83.9	1.1	5.6	5.0	3.4	14.0	1.0
	1956			No classification counts				
	1957			No classification counts				
	1958	80.2	1.2	5.6	5.4	6.8	18.7	0.8
	1959			No classification counts				
	1960			No classification counts				
24-A	1939	84.7	3.2	10.7			10.7	1.4
	1940	82.8	3.9	12.1			12.1	1.2
	1941	84.4	3.9	5.1	2.9	2.4	10.4	1.3
	1942	80.9	4.2	5.6	3.8	3.5	12.9	2.0
	1943	73.2	5.0	7.8	6.1	5.1	19.0	2.8
	1944	70.7	5.7	7.5	6.7	6.1	20.3	3.3
	1945	79.6	4.4	5.4	3.7	4.7	13.8	2.2
	1946	82.8	3.9	4.7	3.4	3.6	11.7	1.6
	1947	82.2	3.9	4.6	3.6	4.1	12.3	1.6
	1948	81.1	5.0	4.3	4.8	3.3	12.4	1.5
	1949	82.1	4.7	4.4	3.8	3.8	12.0	1.2
	1950	79.1	8.4	3.3	3.4	4.3	11.0	1.5
	1951	88.2	0.5	4.0	4.1	2.2	10.3	1.0
	1952	84.7	0.9	4.5	4.5	4.6	13.6	0.8
	1953			No classification counts				
	1954			No classification counts				
	1955	82.0	1.0	5.4	6.2	4.5	16.1	0.9
	1956[5]			No classification counts				
	1957	85.5	1.0	7.5	3.7	1.4	12.6	0.9
	1958	85.8	0.9	8.0	3.5	1.1	12.6	0.7
	1959			No classification counts				
	1960			No classification counts				
24-S	1957	83.3	0.3	3.7	6.0	6.2	15.9	0.5
	1958	81.8	0.4	4.0	6.7	6.6	17.3	0.5
	1959			No classification counts				
	1960			No classification counts				

[1] Data furnished by Oregon State Highway Department.
[2] 1951 to 1960—including passenger cars, panels, and pickups.
[3] 1939 to 1950—including panels and pickups.
[4] 1939 and 1940—including truck and trailer combinations.
[5] Pacific Freeway opened to Portland in November.

TABLE 5

TRAFFIC SPEED[1], PORTLAND TO GRANTS PASS

PASSENGER VEHICLES

Vehicle Type	Year	Traffic Speed (mph)		
		Station 24 - 1	Station 24 - 2[2]	Station 24 - 3[3]
Passenger	1949	52.6	-	52.2
	1950	53.0	-	53.6
	1951	53.2	-	55.3
	1952	49.5	-	52.4
	1953	52.1	-	50.0
	1954	51.0	-	Not available
	1955	49.9	-	53.6
	1956	50.1	63.1	54.1
	1957	50.4	63.2	52.0
	1958	51.3	63.1	54.4
	1959	52.2	63.8	61.1
	1960	52.4	64.7	63.5
Commercial	1949	42.5	-	45.6
	1950	45.9	-	46.9
	1951	46.1	-	48.7
	1952	43.6	-	45.5
	1953	44.5	-	44.2
	1954	43.5	-	Not available
	1955	43.2	-	44.7
	1956	44.5	46.7	45.8
	1957	43.6	48.4	44.4
	1958	44.9	48.4	47.0
	1959	45.7	48.9	48.1
	1960	46.7	50.3	50.1

[1] Data furnished by Oregon State Highway Department.
[2] Station established in November 1956, subsequent to opening of Interstate Route I-5.
[3] Highway at this location constructed to freeway standards in 1959.

TABLE 6

CONSTRUCTION, IMPROVEMENT AND MAINTENANCE COSTS, PORTLAND TO SEATTLE

Year	Construction and Improvement Costs ($)				Maintenance Costs ($)	
	East End, Broadway Br. to Ore.-Wash. State Line[1]		Ore.-Wash. State Line to Seattle[2]		East End, Broadway Br. to Ore.-Wash. State Line[1]	Ore.-Wash. State Line to Seattle[2]
	Affecting Traffic	Aesthetic Value Only	Affecting Traffic	Aesthetic Value Only		
Before 1935	1,473,279	-	18,167,394	-	13,903	Not available
1935	5,502	-	638,092	-	7,702	Not available
1936	7,520	-	888,540	-	8,441	Not available
1937	3,764	-	1,586,122	3,736	15,957	142,897
1938	26,072	-	445,621	-	17,432	134,504
1939	167,570	-	137,341	-	15,230	147,698
1940	40,012	-	14,822	12,686	16,371	172,164
1941	543,979	-	1,515,172	6,518	16,180	161,252
1942	140,298	-	887,237	-	15,909	175,142
1943	336,739	-	89,714	-	17,469	172,593
1944	63,926	-	391,602	613	20,883	175,181
1945	739	-	1,014,496	-	20,380	216,989
1946	39,024	-	986,533	-	28,291	262,555
1947	173,777	-	3,099,263	-	29,112	246,688
1948	52,757	-	1,982,858	47,442	42,775	287,673
1949	97.486	-	3,475,301	38,256	54,945	363,444
1950	69,320	-	2,895,167	34,113	55,472	343,555
1951	39,947	-	5,270,957	5,030	54,356	412,780
1952	22,960	19,874	9,365,338	21,007	57,918	413,158
1953	140,340	143,415	8,270,477	2,110	55,406	460,420
1954	47,694	-	13,985,559	3,478	68,005	493,427
1955	54,805	-	9,126,157	7,219	66,384	473,162
1956	11,722	-	11,415,333	5,027	83,055	580,016
1957	62,878	5,590	9,380,063	37,826	68,238	494,089
1958	7,341,847[3]	-	16,411,359	23,653	92,284	616,773
1959	55,359	20,742	12,512,346	-	87,588	567,198
1960	3,675,170[3]	21,303	6,542,536	11,974	38,813	Not available

[1] Data furnished by Oregon State Highway Department.
[2] Data furnished by Washington State Department of Highways.
[3] Building of new parallel structure and rebuilding of old structure to provide one-way flow of traffic across Columbia River between Portland and Vancouver.

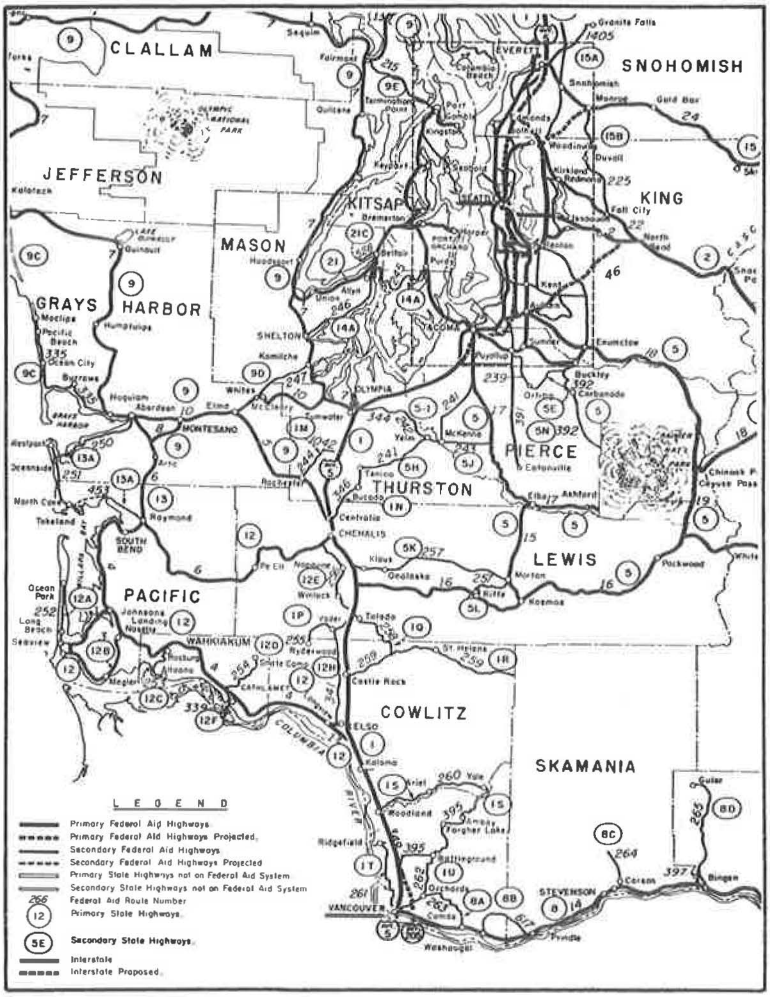

Figure 5. Truck route between Portland and Seattle (Interstate Highway Route 5).

not kept pace with expenditures for highway construction and improvement. This is indicated by the ratios of annual maintenance costs to cumulative construction and improvement costs, using the adjusted data on which Figure 6 is based. The overall average for the period 1935-60 may be computed as 0.0056, but the figures for 1952-60 are given in Table 7. Because maintenance costs are due to such factors as the age of highway, degree of use, and local weather conditions, as well as to the magnitude of the system as measured by expenditures for new construction and improvement, the observation indicated by the preceding statistics is not surprising.

Point-to-Point Mileage.—According to the Oregon State Highway Department, the distance between the east end of the Broadway Bridge in Portland and the Oregon-Washington State Line is 7.17 mi; the mileage has remained unchanged from 1935 through 1960. Route miles between the State Line and Seattle are given in Table 8, and the total route miles between Portland and Seattle are shown in Figure 7.

Overall reduction in distance during the 1936-60 period is, of course, quite evident. Decrease in mileage from 186.54 (in 1935) to 162.40 (in 1960) represents a reduction of 24.14 mi, or an improvement of approximately 13 percent. Moreover, because the straight-line distance from Portland to Seattle is about 133 mi, the reduction in mileage represents a 45 percent improvement when compared to the theoretical minimum.

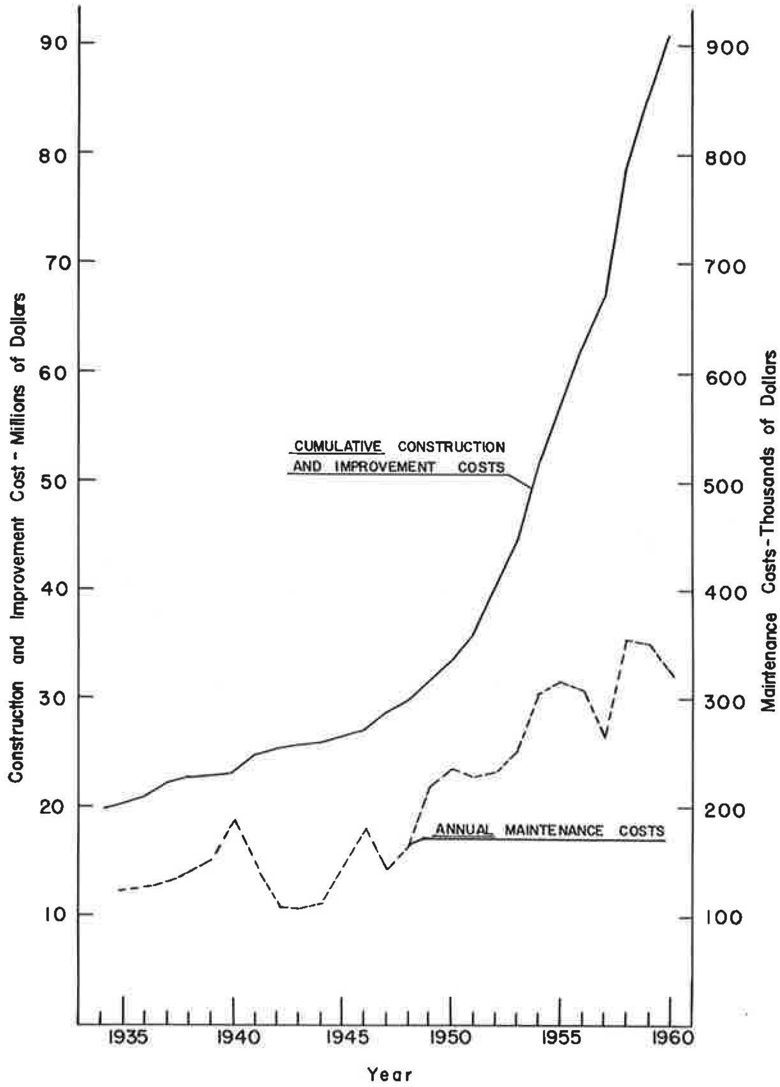

Figure 6. Construction, improvement and maintenance costs, Portland to Seattle, adjusted by Oregon and Washington construction cost indexes (1940 = 100) except for years before 1935.

This figure is derived as follows:

$$\frac{186.54 - 162.40}{186.54 - 133.00} = \frac{24.14}{53.54} = 45\%$$

The percentage improvement based on the theoretical minimum distance was also 45 percent for the Portland-Grants Pass highway.

Although not the major subject of this paper, such similarities are of interest in that they suggest development of standard data that may be useful to other researchers in the highway field.

TABLE 7

MAINTENANCE, CONSTRUCTION, AND IMPROVEMENT COSTS, 1935-60

Year	Annual Maintenance Cost ($)	Cumulative Construction and Improvement Cost ($)	Ratio[1]
1952	232	40,450	0.0057
1953	251	44,503	0.0056
1954	302	51,931	0.0058
1955	314	57,239	0.0055
1956	305	62,434	0.0049
1957	264	66,790	0.0040
1958	354	78,941	0.0045
1959	349	85,559	0.0041
1960	322	91,061	0.0035

[1]Of maintenance to construction and improvement costs.

Average Daily Traffic. —The Washington State Department of Highways has provided traffic density (and traffic distribution) data collected at some 37 points on the Portland-Seattle highway. Because the general pattern of traffic growth is roughly the same at all of these points, statistics from only three data-collection stations have been included (Table 9):

1. C.S. 0601, Interstate Bridge, Oregon-Washington State Line,

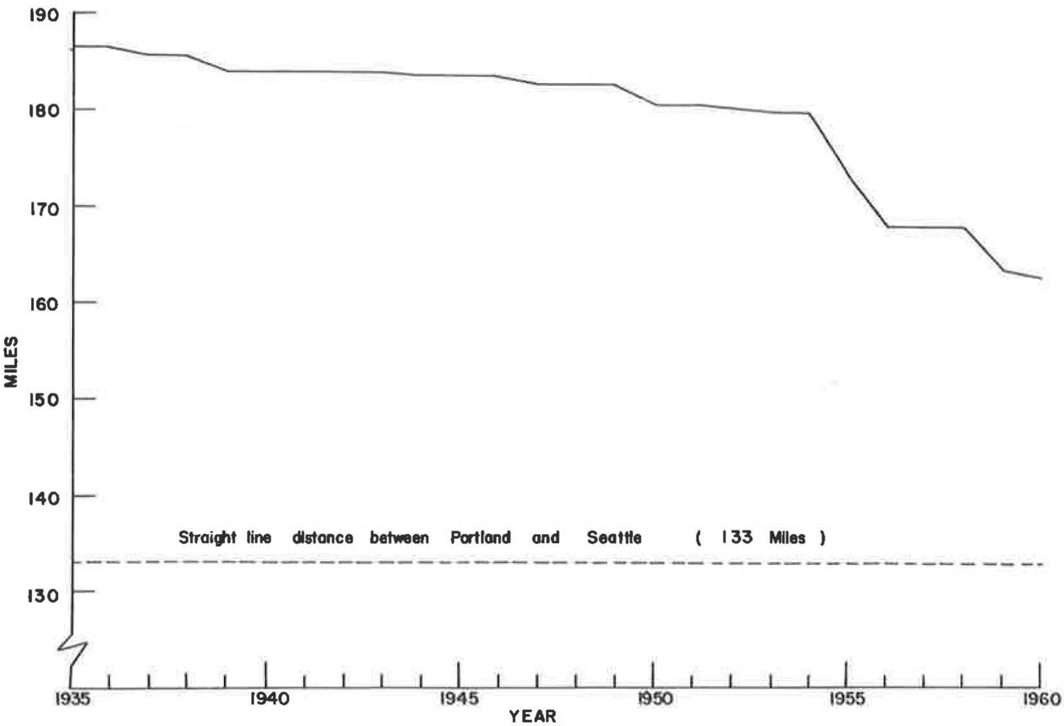

Figure 7. Length of route used by Consolidated Freightways' trucks, Portland and Seattle.

2. C.S. 0603, on US 99, Clark County, and
3. C.S. 1701, on US 99, King County.

Station C.S. 0603 is located in a rural area in the southern part of Washington. Station C.S. 1701, on the other hand, is located between Seattle and Tacoma, a heavily traveled area. Statistics representing traffic density as recorded at these two stations are shown in Figure 8. It is clear that the period since World War II has witnessed a steady increase in highway usage, although most highway analysts believe that it is reasonable to expect that the growth will not continue at the same rate. Parenthetically, it would be interesting to compare present-day traffic usage statistics with predictions made in, say, the 1930's. It is probable that one would find such predictions to have been remarkably conservative.

TABLE 8

LENGTH OF ROUTE, PORTLAND TO SEATTLE

Year	Route Length (mi)	
	Between Ore.-Wash. State Line and Seattle[1]	Between Portland and Seattle[2]
1935	179.37	186.54
1936	179.37	186.54
1937	178,39	185.56
1938	178.39	185.56
1939	176.56	183.73
1940	176.56	183.73
1941	176.56	183.73
1942	176.56	183.73
1943	176.56	183.73
1944	176.09	183.26
1945	176.09	183.26
1946	176.09	183.26
1947	175.23	182.40
1948	175.23	182.40
1949	175.23	182.40
1950	173.19	180.36
1951	173.19	180.36
1952	172.86	180.03
1953	172.30	179.47
1954	172.30	179.47
1955	165.93	173.10
1956	160.48	167.65
1957	160.51	167.68
1958	160.51	167.68
1959	155.94	163.11
1960	155.23	162.40

[1]Data furnished by Washington State Department of Highways. [2]Includes 7.17 mi between Broadway Bridge in Portland and Oregon-Washington State Line.

Traffic Composition.—Table 10 summarizes the percentage of trucks, buses, and pickups observed at the three data-collection stations. On reviewing the data, the following observations were made. First, there is no apparent change in traffic composition over time. The percentage of commercial vehicles has risen slightly over the past fifteen years at C.S. 1701, but fallen slightly at C.S. 0603. Second, it is difficult to determine any difference in percentages between locations—during the ten-year period 1950-59, both C.S. 1701 and C.S. 0603 reported that the percentage of total traffic composed of commercial vehicles ranged between 15 and 17 percent. Finally, these statistics are quite similar to those reported by the Oregon State Highway Department (Table 4).

Traffic Speed.—No statistics describing actual vehicle speeds were furnished by the Washington State Department of Highways, although considerable data concerning vehicle legal speed limits were provided for the period 1949-60. The maximum speed for commercial vehicles was 40 mph between 1949 and 1954, and was 50 mph from 1955 through 1960. This compares to the Oregon truck speed limits of 45 mph for the 1949-57 period, and 50 mph between 1957 and 1960.

THE HIGHWAY USER

Routes

The largest freight terminal of Consolidated Freightways (at the time of preparation of this report) is located in Portland. This terminal not only trades freight with such major distribution areas as Seattle, Spokane, Los Angeles, and Chicago but also is a "break bulk" or "consolidation" point for freight originating or terminating in smaller communities in northwest Oregon. Portland is also a principal point for freight moving up and down the West Coast of the United States. It should be noted that this discussion

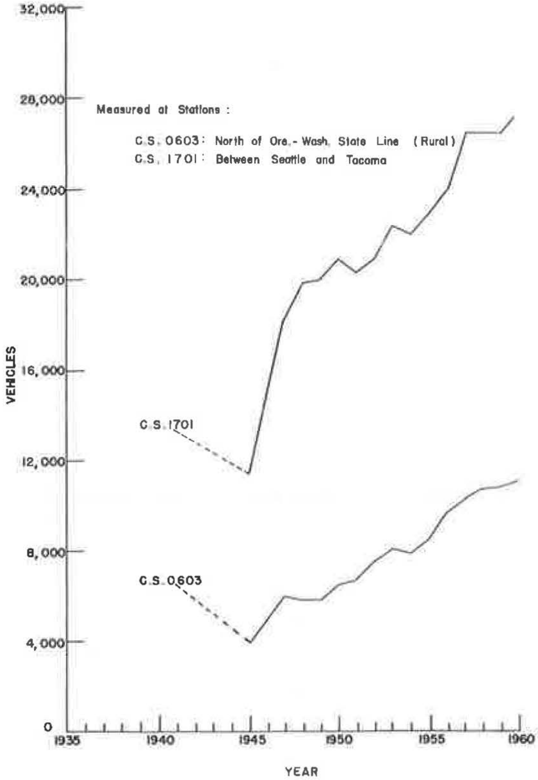

Figure 8. Average daily traffic, Portland to Seattle.

TABLE 9

AVERAGE DAILY TRAFFIC[1], PORTLAND TO SEATTLE

Year	Average Daily Traffic		
	C.S. 0601	C.S. 0603	C.S. 1701
1941	19,100	6,500	13,300
1945	24,600	3,900	11,400
1946	26,500	4,900	14,800
1947	29,100	6,000	18,300
1948	31.900	5,800	19,800
1949	29,100	5,800	20,000
1950	31,600	6,500	20,900
1951	32,200	6,700	20,300
1952	34,500	7,600	20,900
1953	30,400	8,100	22,400
1954	29,800	7,900	22,000
1955	32,400	8,500	22,900
1956	34,400	9,700	24,000
1957	33,800	10,300	26,500
1958	35,200	10,800	26,500
1959	38,500[2]	10,900	26,500
1960	33,000	11,100	27,500

[1] Data provided by Washington State Department of Highways. [2] Second Interstate Bridge added.

of Consolidated Freightways traffic moving on the two subject highways is not necessarily composed only of freight moving between Portland and Grants Pass or Portland and Seattle. For example, freight moving between points in California and Seattle will use both sections of highway. Other examples of traffic moving on trucks that use one or both of the subject highway are shipments moving between San Francisco-Spokane, Phoenix-Seattle, and Los Angeles-Vancouver, B. C.

Consolidated Freightways' vehicles moving between Portland and Grants Pass used US 99E before 1956. In that year, a large freeway section was completed between Salem and Portland, thus causing a change in routing. The Company's trucks currently use Interstate Highway Route 5 between Portland and Grants Pass, this is, in great part, what was formerly known as US 99E. Trucks moving between Portland and Seattle use Interstate Highway Route 5 shown in Figure 5.

TABLE 10

PERCENTAGE OF AVERAGE DAILY TRAFFIC THAT IS TRUCKS, BUSES AND PICKUPS, PORTLAND TO SEATTLE

Year	Percentage Trucks, Buses and Pickups		
	C.S. 0601	C.S. 0603	C.S. 1701
1941	8	-	14
1945	-	21	14
1946	-	19	13
1947	11	21	15
1948	11	21	13
1949	-	19	14
1950	-	15	16
1951	-	17	16
1952	-	16	15
1953	14	15	17
1954	-	15	16
1955	-	17	16
1956	-	17	16
1957	-	-	16
1958	-	-	16
1959	-	-	16
1960	-	-	19

Operations

Before about 1958, the general procedure required a driver to pick up freight in, say, Portland and move it to Seattle. He would then remain in Seattle until the next evening, whereupon he would return to Portland with another load. Typically, the driver would depart the origin terminal between 7:00 PM and midnight, and arrive at the destination terminal between 2:00 and 6:00 AM. The exact departure and arrival times vary, depending on such factors as freight-handling operations at the origin terminal, availability of trucks and drivers, and road conditions. Nevertheless, to provide overnight service between Portland and Seattle, it is necessary that freight picked up one day be processed and delivered at its destination by the morning of the next business day.

Beginning about 1958, it was found that the driving time between Portland and Seattle was reduced to the point where it was feasible to have the drivers make a round trip during one shift. During the period 1935 to the early 1950's it usually took from five to seven hours to travel between Portland and Seattle. And because drivers are paid overtime for all hours worked over eight, the additional overtime pay entailed in a one-shift round trip was deemed prohibitive. By 1958, however, driving conditions had improved to the point where a schedule could travel one-way in only four or five hours; thus, a driver could make a round trip in nine hours or so. Because of the reduced overtime required, the Company, with the concurrence of the Union, decided to begin round trip operations. The Company's operating personnel in Portland have indicated that approximately 40 percent of the drivers currently operating from Portland to Seattle return during the same shift. Driving time between cities has clearly not been sufficiently reduced to the point where all drivers can make a single round trip.

Consolidated Freightways' trucks moving between Portland and Grants Pass have experienced a similar drastic change in operating pattern beginning at a particular point in time. During the 1940's for example, the driving time between these two points was about eight or nine hours—just about the right number of hours to make up a driving shift with minimal overtime. Due to improvements in the highway, however, this on-the-road time was reduced to about seven hours by the late 1950's. Consequently, in 1960, the Company moved its driver layover point (sometimes called "division point") from Grants Pass to Medford, some 30 mi further south on the highway. Freight destined for Grants Pass is currently shipped to Medford where it is transshipped by local pickup and delivery trucks operating from the Medford terminal.

The Company was clearly able to eliminate its Grants Pass terminal and increase the number of miles per driver-hour paid for by this change in operations. Moreover, there were formerly three such division points between Portland and the San Francisco Bay Area. But with the reduction in driving time brought about by highway improvements, the Company was able to reduce these to two in 1960. The shift from Grants Pass to Medford was part of this change. Again, it is emphasized that the impact on trucking operations, in an economic sense, took place at a definite point in time rather than gradually over a long period.

(Large-scale trucking operations involving long distances and a great many points of origin and destination are necessarily quite complex. The preceding discussion attempts to simplify these complexities while retaining those elements essential to the development of this paper—a full and accurate description of all possible operating characteristics would be beyond the scope here. Nevertheless, it is believed that the generalizations that have been employed will in no way detract from the validity of the remaining discussion.)

Equipment Changes

Consolidated Freightways has operated a variety of types of equipment over routes in the Northwest during the last 25 years. Because of the legal restrictions of the States in which it operates, need for flexibility in assignment of equipment geographically, variations in terrain, etc., it is infeasible for the Company to maintain a homogeneous fleet at one point in time. Moreover, such factors as equipment design improvements and changes in legal restrictions are responsible for altering the general composition

TABLE 11

HISTORICAL TRAVEL TIMES FOR BUSES[1], PORTLAND-GRANTS PASS AND PORTLAND-SEATTLE

Year	Travel Time (hr: min)			
	Between Portland and Grants Pass		Between Portland and Seattle	
	Local	Express	Local	Express
1936	8:53	8:02	6:45	6:45
1937	8:56	8:08	6:45	5:15
1938	8:28	7:59	6:30	5:15
1939	8:28	7:59	6:15	5:15
1940	8:28	7:59	6:15	5:15
1941	8:21	7:49	6:15	5:15
1942[2]	9:38	9:12	6:40	6:40
1943[2]	9:48	9:46	7:45	7:45
1944[2]	9:12	8:59	7:45	7:45
1945[2]	9:12	8:59	7:45	7:45
1946	8:30	8:12	6:55	5:30
1947	8:13	8:08	6:40	5:35
1948	8:25	8:16	6:50	5:35
1949	8:40	6:44	6:50	5:20
1950	8:11	6:54	6:40	5:35
1951	8:11	6:54	6:40	5:35
1952	8:15	6:23	6:45	5:25
1953	8:15	6:51	6:45	5:20
1954	8:15	6:52	6:45	5:30
1955	8:15	6:27	6:40	5:05
1956	8:15	6:30	6:45	4:15
1957	8:15	6:30	6:25	4:15
1958	8:06	6:40	6:45	4:15
1959	8:06	6:40	6:35	4:15
1960	7:46	5:50	6:03	4:15

[1] Figures, representative times of actual schedules, provided by Western Greyhound Lines.
[2] A 35-mph speed limit imposed by U.S. Office of Defense Transportation from 1942 through 1945.

of the truck fleet over a period of years. The following remarks, then, apply to "typical" vehicles used by the Company between Portland-Seattle and Portland-Grants Pass.

Prior to 1938[1], the Company operated 90-hp gasoline engine, four-wheel tractors with full trailers on the subject highways. The horsepower rating of these tractors was increased to 120 hp in 1939. The Company converted to diesel-powered tractors in 1942, rated at 150 hp; and six-wheel tractor, six-wheel full trailer combinations were introduced in 1944.

The next major equipment change occurred in 1948 when 220-hp diesel tractors began to be used. The rating of these engines was increased to 280 hp in 1951 and increased again to 285 hp in 1953. Two semitrailers hauled in tandem were substituted for the single full trailer beginning in 1955 in order to increase cargo-carrying capacity. No additional significant equipment changes took place between 1955 and 1960.

It is believed that these changes are similar to those experienced by truck operators in other parts of the United States. Inasmuch as technological improvement and the continuing search for increased productivity are well established in fact, it is reasonable to expect analogous advancement in the future.

[1] All dates pertaining to equipment usage are approximate.

Travel Time Between Points

Two methods have been used in an attempt to reconstruct the historical driving times between Portland-Grants Pass and Portland-Seattle. The first of these is based on the records of a scheduled carrier of passengers, Western Greyhound Lines. Through the generous cooperation of the Company, passenger time schedules were provided showing departure and arrival times for both express and local buses using the subject highways during the period 1936-60.

Table 11 shows the historical running times between points, and includes only actual road times between origin and destination cities. The data pertaining to local buses include delay times at local stops and are therefore poor indicators of truck travel times. On the other hand, express bus data reflect only time spent on the road between origin and destination, and are thus considered to be good approximations of time spent by trucks traveling over the same routes. Express bus travel time is shown in Figure 9.

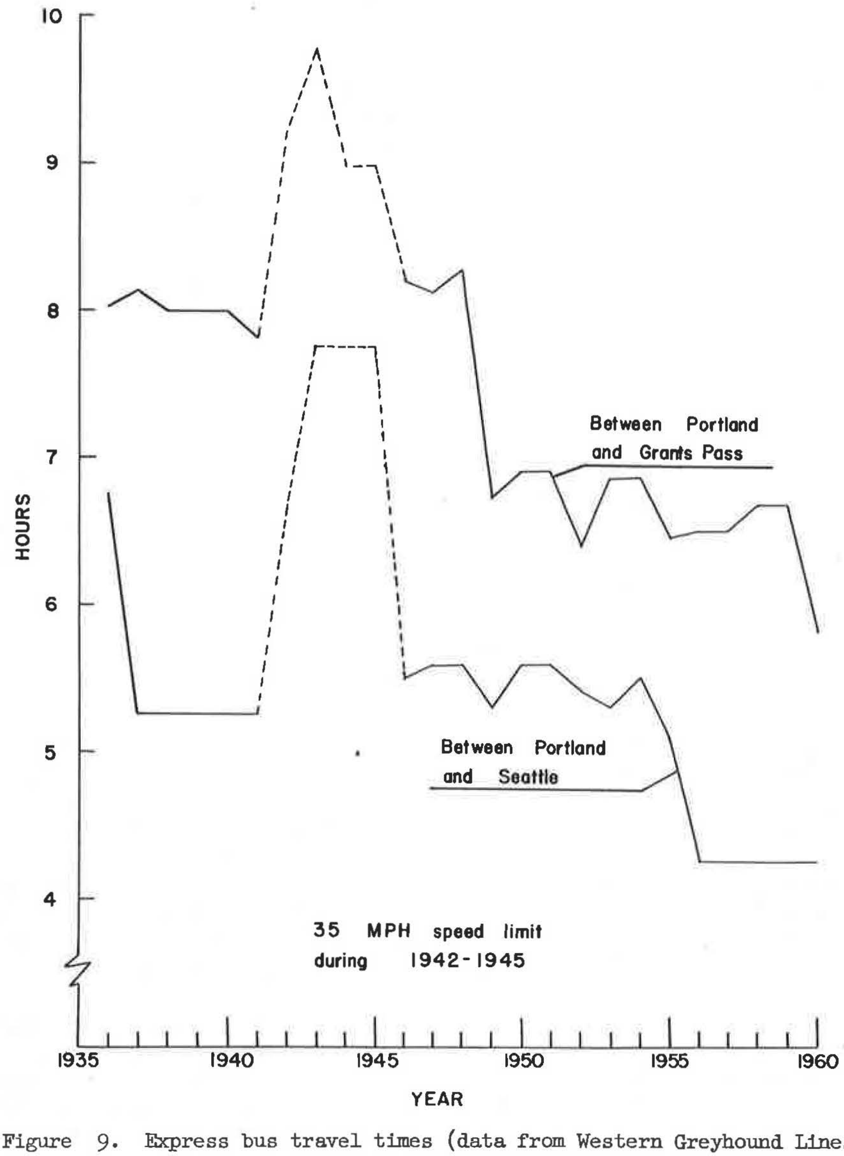

Figure 9. Express bus travel times (data from Western Greyhound Lines).

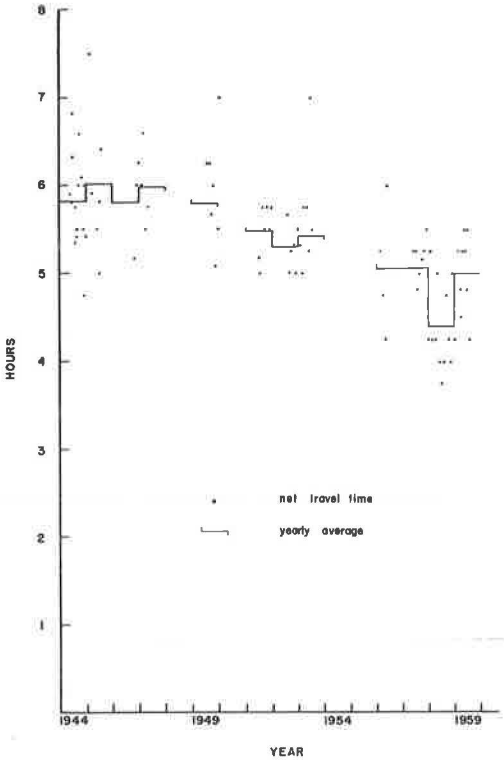

Figure 10. Truck travel times between Portland and Seattle.

TABLE 12

HISTORICAL TRAVEL TIMES FOR TRUCKS BETWEEN PORTLAND AND SEATTLE

Year	Travel Time (hr: min)	
	Sample Size	Average Driving Time
1944	15	5:49
1945	7	6:02
1946	3	5:48
1947	4	5:59
1948	-	-
1949	6	5:48
1950	-	-
1951	7	5:29
1952	6	5:18
1953	6	5:26
1954	-	-
1955	-	-
1956	4	5:04
1957	8	5:04
1958	12	4:24
1959	12	5:00

The second method used for determining historical travel times for Consolidated Freightways' trucks proved considerably more difficult. It was hoped that records of departure and arrival times would have been retained by the Company, but such was not the case. At any rate, some of the older drivers were consulted, and they estimated driving times between Portland and Grants Pass as follows:

1938	10 hr
1943	9 hr
1947	8 hr
1960	7 hr

Fortunately, greater success was achieved with regard to trips between Portland and Seattle. Through a series of inquiries in the Portland area, a valuable, though incomplete, set of driver log books was uncovered. A sample of trip information was taken from each of the available log books, the sample being selected in such a way as to insure adequate seasonal representation. Actual driving times between Portland and Seattle were determined by considering time of departure from one city and time of arrival at the next, subtracting all time in stops (for whatever reason) along the road. The results are shown in the form of a scatter diagram in Figure 10. Next, yearly average driving times were determined by taking the mean of the sample points for each year (Table 12).

The data in Figure 10 show a wide range of driving times, even within a single year. This variability is primarily explained by trip-to-trip differences in such factors as traffic and weather conditions. Nevertheless, a clear pattern of decreasing driving time is indicated—a reduction from about six to five hours seems to have been effected during the fifteen years after World War II. (The Greyhound Lines' express bus statistics were approximately 5.5 and 4.5 hr, respectively, during this same period.)

A comparison of travel times between cities for Consolidated Freightways' trucks and Greyhound express buses indicates (a) bus times have always been less than truck times, and (b) the gap has been narrowing in recent years. The first phenomenon is largely explained by the superior operating characteristics of buses, particularly with regard to maneuverability in traffic and ability to traverse highways with extreme grades. Because continued improvements in highways tend to mitigate these advantages, narrowing of the gap between bus and truck travel times is to be expected.

All trip times discussed in this section are "pure" in the sense that they exclude all routine and nonroutine stops made by the vehicle while traveling from origin to destination. Dinner stops, equipment breakdown, etc., have been omitted in order to generate unbiased statistics. The preceding discussion of operations, on the other hand, included total elapsed time between points. Data from the driver log books indicate that an additional 30 to 45 min of delay time per one-way trip should be added to driving time in order to compute total elapsed time between Portland and Seattle. The Portland-Grants Pass times discussed earlier represent total elapsed time.

TABLE 13

DRIVER STRAIGHT-TIME DAILY WAGE RATES[1,2]

Oregon Contracts		Washington Contracts	
Period	Wages per 8-Hr Day ($)	Period	Wages per 8-Hr Day ($)
		11/34 - 11/35	7.75
		12/35 - 7/36	-
		8/36 - 1937	8.00
		1937 - 1938	8.75
3/41 - 3/43	8.75	1938 - 1941	-
3/43 - 3/44	9.80	4/41 - 11/41	9.00
3/44 - 3/45	9.80	5/42 - 4/43	10.00
3/45 - 3/46	10.05	4/43 - 1944	10.00
3/46 - 10/46	11.00	1944 - 1945	10.00
10/46 - 1/47	11.50	1945 - 1946	10.50
1/47 - 3/47	11.75	1946 - 1947	11.25
3/47 - 5/48	12.00	1947 - 5/48	13.00
5/48 - 5/49	13.50	5/48 - 5/49	13.80
5/49 - 5/50	13.60	5/49 - 5/50	14.36
5/50 - 5/52	14.00	5/50 - 5/51	14.76
5/52 - 8/52	15.50	5/51 - 5/52	15.26
8/52 - 3/54	16.16	5/52 - 5/54	16.16
3/54 - 5/55	17.12	5/54 - 5/55	17.12
5/55 - 5/56	17.76	5/55 - 5/56	17.76
5/56 - 5/57	18.40	5/56 - 5/57	18.40
5/57 - 5/58	18.96	5/57 - 9/58	18.89
5/58 - 5/59[3]	19.76	9/58 - 5/59	19.76
5/59 - 5/60[3]	20.56	5/59 - 5/60	20.56
5/60 - 5/61[3]	21.36	5/60 - 5/61	21.36

[1]Data source: Teamster's Union contracts.
[2]Line haul drivers only, truck and trailer or tractor and semitrailer over 125 mi.
[3]Based on hourly rather than mileage pay.

Payments to Drivers

Hourly Wages.—Determination of wage data is complicated by the various factors on which wages are computed. For example, different contracts apply in different geographical areas[2], wages depend on the type of equipment being operated, and, particularly in recent years, wages may be computed on an hourly or mileage basis.

The daily straight-time wages given in Table 13 and (Fig. 11) are believed to be typical of those paid to operators of commercial vehicles on the Portland-Grants Pass and Portland-Seattle highways. Specifically, the wages as shown are based on (a) an eight-hour day, (b) payments made to line haul drivers rather than local pickup and delivery drivers, (c) operators of truck and trailer or tractor and semitrailer vehicles, and (d) for trips of more than 125 mi in length in any one day. Only one increase in wages is noted during the World War II period due to government restrictions. Another period of relatively stable wage levels occurs around 1950. This is probably explained by the Union emphasis on winning increased fringe benefits; e.g., six paid holidays were initiated in May 1950.

An important though often overlooked aspect of wage payments to drivers is the contractual obligation to provide a minimum number of hours of pay. That is, if a driver is called to work on a specific day, the company is obliged to pay him for at least a certain number of hours, regardless of the time actually worked. Washington contracts required a four-hour minimum pay period until 1943, at which time the minimum was increased to eight hours. Minimum periods were the same under Oregon contracts, except that the increase from four to eight hours occurred in 1948. It will be recalled that the Portland-Grants Pass and Portland-Seattle trips have always involved at least

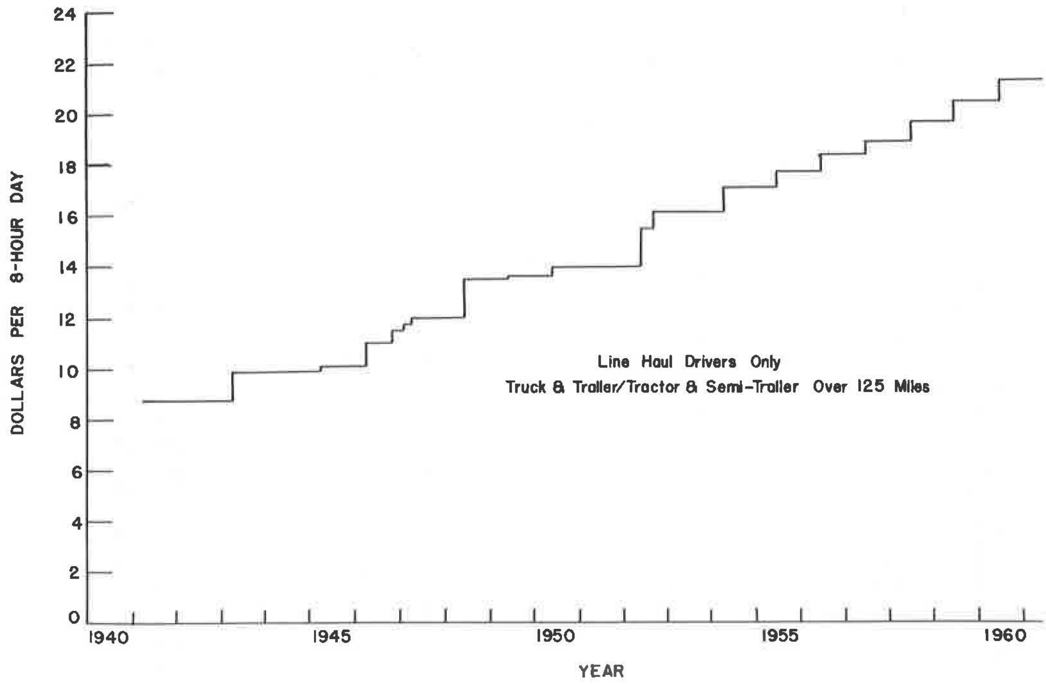

Figure 11. Straight-time daily wage rates, Oregon-based drivers.

[2]This was the case before the late 1950's, but the trend in recent years has been towards uniformity throughout the West.

TABLE 14

DRIVER WAGE PAYMENT SCHEDULE

Period	Wage Payment ($/mi)	
	For Less than 250 Mi Driven	For over 250 mi Driven[1]
5/58 - 5/59	0.08⅛	0.08⅝
5/59 - 5/60	0.08⅜	0.08⅞
5/60 - 5/61	0.08⅝	0.09⅛

[1]By one driver without intervening rest period.

four hours of driving time. Therefore, for all practical purposes, an eight-hour minimum wage should be considered.

Although both Washington and Oregon wage data are presented, it is probably most reasonable to consider only wages paid under Oregon contracts within the context of this paper. This is so because drivers operating on the Portland-Grants Pass and Portland-Seattle routes are primarily based in Portland. Moreover, all of the extra (nonscheduled) trips operating between Portland and Seattle originate in Portland.

Two observations can be made at this point concerning the contractual restrictions discussed in the preceding paragraphs. First, proper economic analysis should recognize that only increments in wages paid are relevant. For example, a reduction in trip time from seven to six hours clearly results in no incremental decrease in driver pay. Furthermore, a reduction in trip time from nine to eight hours not only results in a savings of one full hour of wages, but this should be incrementally valued at the overtime wage rate. A second observation is that drivers are paid for total trip time rather than simply time actually spent driving the vehicle. Thus it is necessary to consider the effect of decreased driving time on nondriving activities (such as rest stops) in order to evaluate the economic consequences of highway improvement properly.

Mileage Pay.—In May 1958, a major contractual change occurred which should be of considerable interest to highway economic analysts. At that time, the contracts were revised to provide for wage payments to drivers on either an hourly or mileage basis, whichever is greater, according to the schedule in Table 14. The point at which the mileage rate exceeds the hourly rate occurs at 239 mi.

An interesting aspect of this "new" type of wage payment is the effect it might have in evaluating the beneficial consequences of highway improvement, for now the analyst must consider mileage rather than hourly wage rates in some instances. It is misleading, however, to believe that a reduction of one mile in route length means a corresponding reduction of one mile of driver pay. This is so because the most recent contracts specify that, in the event of such a reduction, the company may reduce the driver's wage only over a period of six years from the date of the reduction at the rate of one-sixth per year. For example, suppose a driver has been driving a 300-mi route and the highway has been improved to the point where the route is now only 294 mi. The driver's pay will then be reduced by $0.09⅛ per trip each year over a period of six years, until it has finally been reduced by $ 0.54¾. Thus, even under the mileage payment plan, there is a time lag between the date of the improvement and the date at which the improvement is fully economically meaningful to the company. During the six-year postimprovement period, both the drivers and the company share in the benefits in varying proportions.

Incremental Fringe Benefits.—There are, of course, costs associated with so-called fringe benefits which add to the variable cost of driver labor. Consolidated Freightways reports the following categories of fringe benefits, most or all of which are paid under the various contracts:

1. State workmen's compensation.

2. State unemployment.
3. Federal unemployment.
4. Federal Insurance Contributions Act (FICA).
5. Health and welfare.
6. Pension.
7. Holidays.
8. Vacations.
9. Cost of living increases.

Although most of these are fixed in the sense that their cost is independent of the driver's direct wages, some of them are meaningful when considered incrementally. That is, State compensation, vacations, and cost of living increases vary directly with gross pay and thus should be considered by the highway economic analyst. That is, a reduction in $1.00 of driver wages also results in a decrease in the corresponding appropriate fringe benefits. The incremental fringe benefits recently paid by Consolidated Freightways are summarized in Table 15.

There are other fringe benefits, such as State unemployment and FICA, which are also based on wages; e.g., FICA is presently 3⅛ percent of the first $4,800 of annual earnings. But inasmuch as drivers usually earn far in excess of these base amounts,

TABLE 15

INCREMENTAL FRINGE BENEFITS[1]

Type of Benefit	Date	Minimum Employment (yr)	Rate of Benefit
Washington Workmen's Compensation	1958	-	3.79% of gross wages
	1959	-	4.28% of gross wages
	1960	-	4.24% of gross wages
	1961	-	4.57% of gross wages
	1962	-	5.06% of gross wages
Oregon Workmen's Compensation[2]	1958	-	0.790% of gross wages
	1959	-	0.605% of gross wages
	1960	-	0.682% of gross wages
	1961	-	0.737% of gross wages
	1962	-	0.825% of gross wages
Cost of living increases	8/1/59	-	$0.01 above regular contract increases
	2/1/60	-	$0.02 above regular contract increases
	8/1/60	-	$0.01 above regular contract increases
	2/1/61	-	$0.02 above regular contract increases
Vacations	1961	1[3]	1/52 of gross pay
		3	2/52 of gross pay
		11	3/52 of gross pay
		18	4/52 of gross pay

[1] Data provided by Keith Anderson, Cost Accountant, Consolidated Freightways, Inc.
[2] Workmen's Compensation rates in Washington are compulsory and Oregon is self-insured. This is reason for large variations in percentages.
[3] Vacation benefit for drivers having less than one year's service, but hired prior to July 1, 1961, was $^1/_{35}$ of gross pay.

TABLE 16

SUBSISTENCE PAY AT DIVISION POINTS[1]

Contracts	Period	Subsistence Pay per Day ($)
Oregon	Before 1946	0.00
	5/1/46 - 5/1/48	1.00
	5/1/48 - 5/1/51	1.50
	5/1/51 - 5/1/52	2.00
	5/1/52 - 5/1/53	3.00
	5/1/53 - present	4.50
Washington	Before 1947	0.00
	1947 - 1949	1.00
	1949 - 11/1/50	2.00
	11/1/50 - 5/1/53	3.00
	5/1/53 - present	4.50

[1]Data source: Teamster's Union contracts.

they have no relevance in an incremental sense. That is, a small incremental reduction in driver wages will not affect costs due to these fringe benefits.

Subsistence Allowance.—Beginning in 1946 (Oregon) and 1947 (Washington), contracts have provided for daily subsistence payments to drivers away from their home terminal. For example, Portland-based drivers hauling a load to Seattle one night and returning the following evening are to be paid a subsistence allowance for the day spent in Seattle. (In this example, only one subsistence payment is allowed.) These allowances, as specified by the Oregon and Washington contracts, are given in Table 16.

These subsistence payments are of interest to the highway economic analyst because they may be affected by highway improvement. For example, consider the recent changes in operational scheduling for trucks traveling between Portland and Seattle. As soon as the highway improved to the point where a driver could make a roundtrip in one shift, subsistence payments were no longer necessary. Furthermore, when the number of division points for trucks moving from Portland to the San Francisco Bay Area was reduced from three to two, an additional subsistence payment was thereby eliminated. The economic value to the company of highway improvement, therefore, may consist of reduction in subsistence allowance costs in addition to savings in driver wages. Although Consolidated Freightways has no readily available data indicating the magnitude of these savings, they are believed to be substantial. This clearly appears to be a fruitful area for further research.

SUMMARY AND CONCLUSIONS

Highway Expenditures and Operating Benefits

The two preceding sections, taken together, indicate the effect of highway expenditures on the operations of Consolidated Freightways' trucks using the subject highways during the period 1935-60. Clearly, the States of Oregon and Washington have expended large sums of money in constructing, improving, and maintaining their highway systems during this period (Table 17). Moreover, the largest portion of these expenditures has taken place during the most recent decade. Through 1953, the cumulative (adjusted) construction and improvement expenditures totaled $34,422,000 for the highway between Portland and Grants Pass; at the same time, the total was $44,503,000 for the highway between Portland and Seattle. In both instances, more dollars were expended during the last seven years of record (1954-60) than throughout all the preceding years.

It is equally evident that these expenditures have resulted in marked improvement

TABLE 17

CUMULATIVE CONSTRUCTION AND IMPROVEMENT EXPENDITURES ON SUBJECT HIGHWAYS

Highway	Expenditure[1] ($)	
	Before 1935	Through 1960
Portland-Grants Pass	18,215,000	89,081,000
Portland-Seattle	19,641,000	91,061,000

[1]Cost data after 1935 adjusted by State construction cost indexes.

in operations for vehicles using the highways. For example, Consolidated Freightways' trucks traveling between Portland and Seattle in 1947 required approximately six hours for the one-way trip. By 1959, this had been reduced to less than five hours, allowing the Company to make considerable changes in its operations. Western Greyhound Lines experienced similar benefits; their express buses traveling between Portland and Grants Pass improved their travel time from approximately eight hours in 1936 to less than six hours in 1960.

Still another benefit resulting from highway expenditures is indicated by the traffic density data of Table 9. Here, measurements of ADT were taken before and after improvement of the highway to freeway standards. The demonstrated increase in ADT suggests that it is appropriate to consider that congestion would have increased travel times unless highway facilities had been improved. That is, expenditures for construction, improvement, and maintenance not only reduce highway distance but also are necessary to mitigate the effects of increased traffic density. In a sense, it is necessary to run in order to stand still.

It is dangerous to present historical statistics in a study such as this one, because there is frequently a tendency to extrapolate the data without justification. This comment has particular relevance to the data concerning reductions in route length during the 25-year period. Although the "excess" distances (number of miles in excess of the straight-line distance between points) for both the Portland-Grants Pass and Portland-Seattle highways were almost halved between 1935 and 1960, it is not reasonable to assume that reductions will take place in the future on a similar scale. As noted earlier, such factors as population centers and topography define a traffic lane fairly rigorously. Thus, it is more reasonable to expect that future improvements will be designed not so much to decrease highway distance as to result in such benefits as improved traffic flow and accident reduction. Where distances will not be decreased, operating costs will be increased as speeds increase; hence, considerations of the "trade-off" between decreased time and increased vehicle-operating costs will become a subject of even greater interest to highway economic analysts.

Time Lag

Examination of the operating characteristics of Consolidated Freightways' trucks on the Portland-Grants Pass and Portland-Seattle highways clearly indicates a considerable lag between the point at which time is saved and that at which it can be utilized in an economic sense. The large sums of money spent for highway construction, improvement, and maintenance have resulted in decreased travel times between origin and destination cities. (The inverse relationship between highway expenditures and vehicle speed is evident, despite the increase in traffic density during the 25-year period.) Nevertheless, it has been demonstrated that the Company was unable to take advantage of speed increases until trip time was reduced to the point where operations could be drastically revised.

The lag between physical realization and economic utilization has essentially two interdependent aspects. The first of these, of course, is the lag as measured in number of years. For example, it has been shown that time saved by Consolidated Freightways' trucks between Portland and Seattle in, say, 1948, was worthless until about 1958 when a one-shift turnaround became feasible. An economic analysis attributing dollar benefits to the Company in 1948 would therefore have been in error. That is, the assumption by analysts, so widely held currently, that time savings necessarily have immediate economic value, is fallacious in principle.

The second aspect of this phenomenon is the dollar value of time savings. If time cannot be economically utilized when it is saved, it obviously has no value whatsoever—at least as far as the Company is concerned. But what is its value when utilization finally takes place? The importance of this question is evident when one considers that present methodology normally bases the dollar value of time on current wages. For example, an analyst evaluating the benefits of a highway improvement in, say, the fall of 1948, would probably have credited the project with $1,687 ($13.50 + 8) for each hour of commercial vehicle time saved (using the average straight-time hourly rate). However, if the hour saved does not become economically meaningful until 1958, then a value of $2.47 ($19.76 + 8) may be more appropriate. (This simple example does not imply that the author favors basing the value of time on straight-time hourly wages. It is only used here to indicate roughly the magnitude of changes in the parameter which take place over the span of time between physical realization and economic utilization. Nevertheless, because all present schemes for deriving time value are primarily based on driver wages, these remarks are appropriate[3].)

The primary reason for the lag between the point at which time is "released" by highway improvement and the point at which it becomes economically useful to the carrier is the operational characteristics of the individual company. In the case of Consolidated Freightways' operations between Portland and Seattle, for example, time saved could not be used until a turnaround during a single shift was made possible. An additional reason for this lag may be restrictions imposed by the particular Union contract governing the drivers. It has been noted that drivers are not allowed to handle freight at the origin or destination terminals. If they were, then "released" driving time could be utilized by the Company. Moreover, the employer does not have complete freedom to alter existing work practices, at least not from a practical point of view. Both the new turnaround scheduling at Seattle and the change in "division point" locations from Grants Pass to Medford were effected with the concurrence of the Union.

Economic Value of Time Saved

From the point of view of the company, wages cannot be saved until the driver is allowed to perform the same amount of work in less time, where "time" refers to that which is paid for and not the length of time taken to perform a given task. Because the value of time savings is largely dependent on the operating characteristics of the carrier, it follows that evaluating savings at the straight-time driver wage rate is inappropriate. For example, a highway improvement that reduces trip time from eight to seven hours has no value to the company. If an improvement reduces trip time from, say, five to four hours, and if this reduction allows the drivers to make a turnaround in one shift, then the last added improvement effectively results in a four-hour saving in driver wages. And if an improvement results in a driving time reduction from nine to eight hours, then the hour saved should be evaluated at overtime rather than straight-time wage rates. Moreover, because it is the total of all consequences of a project which is relevant, proper economic evaluation must include incremental fringe benefits such as those discussed earlier under "The Highway User."

Of course, certain economic benefits may accrue to the carrier as the result of highway improvement, even if driver wages may not be immediately reduced. In some cases, for example, drivers are allowed to perform nondriving activities at the origin or destination terminals. (These instances are rare among unionized drivers in the West.) Other opportunities for economically using savings in driver time occurs with

[3]Wage inflation presents no problem under certain conditions (2, p. 6).

regard to scheduling terminal activities and elimination of subsistence payments at "layover points." Still another benefit to the carrier occurs if a time saving permits the same amount of freight to be carried with fewer units of road equipment thereby reducing the carrier's capital costs.

It is clear from the preceding remarks that there are a number of economically meaningful consequences of reduction in driving time. But it is equally apparent that neither has time economic value (to the carrier) as soon as it is released, nor is its value measured by straight-time driver wages. Such assumptions, presently in vogue among highway economic analysts, are conceptually invalid and their continued unquestioned acceptance will in some instances lead to the selection of economically inferior alternatives. (There have been some recent attempts to establish the value of time in a more reasonable manner, but all present methodology persists in the assumption about timing of these benefits.)

The Future

In addition to verifying or disproving a given thesis, historical evidence of the type presented in this paper can also be used to indicate what may be expected in the future.

Additional reduction in vehicle travel time between Portland and Seattle will allow a greater percentage of single shift round trips because present one-way travel time of four and one-half to five hours has resulted in only about 40 percent of the schedules taking advantage of the round trip. Variability in (a) road time and (b) departure time from the origin terminal still causes a large percentage of the schedules to arrive at the destination terminal too late for return during the same shift. It is reasonable to expect that continued reductions in trip time will increase the number of schedules that are beneficially affected although, due to certain other operating characteristics, it is doubtful that 100 percent utilization will ever be accomplished. Future vehicle speed increases between Portland and Grants Pass are not as likely to yield significant economic benefits as those that are in prospect between Portland and Seattle.

Contractual provisions for sharing time savings between management and labor were discussed in the section on "The Highway User." This occurs, it will be recalled, when drivers are paid on a mileage, rather than time basis. Under this payment schedule, wages saved as the result of a reduction in trip length revert to the company at the rate of one-sixth a year for six years. Because contracts are subject to renegotiation, it is possible that future contracts will be written so as to "freeze" the route length for wage payment purposes, to allow the company to take full advantage of the savings, or to share the benefit on some other basis. In any event, this is an obvious example of the effect of labor-management contractual provisions on the value, as well as the timing, of benefits accrued as the result of highway improvement.

Future contract changes that will also be of interest to highway analysts are those relating to wages and fringe benefits. The steady increase in wages over the years since 1935 has been indicated and it seems reasonable to assume that the trend will continue. If all cost factors (other than capital costs) increase at the same rate, then this presents no problem. But, if this is not the case, analysts will have to take note of these changes and make appropriate adjustments to input data used in highway economy studies. Statistics presented earlier in this paper indicate that the problems of prospective rate of increase in wages and its proper treatment in economy studies are worthy of further research.

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Direct Costs and Frequencies of 1958 Illinois Motor-Vehicle Accidents

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Accident experience of owners and operators of Illinois registered passenger cars and trucks during the study year 1958 is related, in terms of costs incurred and accident frequencies, to the various highway systems of the State and to the use of the systems by passenger cars and trucks of different sizes and weights.

A portion of the paper compares accident occurrence and costs in urban vs rural areas, and discusses the impact of the large metropolitan area of Chicago with respect to the total direct cost determination for the State.

An analysis of the various cost elements (property damage, injury treatment costs, value of time lost, legal fees, etc.) that make up the total direct costs of motor vehicle accidents is included.

• THIS PAPER discusses some of the principal findings of the Illinois motor-vehicle accident cost study, a cooperative project of the Illinois Division of Highways and the U. S. Bureau of Public Roads. The study, which was undertaken in 1959, was designed to measure the direct costs of accidents and incidents involving owners of Illinois registered passenger cars and trucks during calendar year 1958 and to relate such costs to the highway, the vehicle, and the persons involved.

The only distinction between a motor-vehicle accident and a motor-vehicle incident is the element of motion. In an incident, there is no motion on the part of the motor vehicle. In general, losses through motor-vehicle incidents include such events as storm damage, acts of vandalism, fires, mishaps occurring during the servicing and repair of a motor vehicle, and collisions of conveyances other than motor vehicles with parked or standing motor vehicles.

Many cost items can be associated with traffic accidents and other mishaps, but cooperative studies of the Bureau of Public Roads and State highway organizations undertaken to date have been concerned only with the "direct costs" of accidents and incidents[1]. A broad but not quite accurate definition is that the Illinois study and previous studies have reflected only the "out-of-pocket" costs. Stated more precisely, the costs were those directly attributable to accidents, and the costs thus determined represented the use of resources that would have been available for other purposes had the accidents not occurred. Cost elements included in the study are discussed in subsequent sections of this paper.

Legal requirements in all States specify that owners must file a report of motor-vehicle accidents involving death or injury. The laws relating to property damage only accidents vary from State to State. In Illinois, the statutory requirement specifies that an accident report must be filed with the State for any motor-vehicle accident involving death or injury, and any accident in which damage to property of any one person exceeds $100.

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[1] Other cooperative studies with the year of survey are passenger car phase—Massachusetts (1953), New Mexico (1955), and Utah (1955); truck phase—Massachusetts (1955), New Mexico (1956), and Utah (1957).

With few exceptions, accident statistics published by various private and public organizations are based solely on official reports of accidents filed with State agencies. Data developed in cooperative studies undertaken by the Bureau of Public Roads have indicated that a substantial part of the accident problem is overlooked by relying only on official accident records. Many accidents occur for which no reports are filed, and although the events are usually minor happenings, they add significantly to the number and cost of accidents.

The Illinois study, as well as previous studies, was designed to determine the direct costs of accidents and incidents ranging from minor fender-denting collisions to the most serious accidents involving death or injury.

SAMPLING PROCEDURE

To attempt a study of statewide vehicle owners' accident experience for a one-year period dictated the use of the sampling method. Two sources were used: owners' accident reports filed with the Illinois Division of Highways, Bureau of Traffic; and registration lists of vehicle owners published by the office of the Secretary of State. Official accident reports filed with the State during 1958 represented the known "population" of motor vehicle accidents. Vehicle owners selected from registration lists represented the unknown area in determining accident and incident occurrence.

Following the procedures of previous State studies, the sampling unit for reported accidents was the license plate number of a privately owned passenger car or truck involved in an accident. Reports on file yielded 320,700 license numbers of Illinois registered passenger cars (or the equivalent thereof) involved in accidents and 26,200 trucks. These data were available on tabulating cards, thus permitting the selection of samples by machine method. The cards were grouped according to severity classes (fatal injury, nonfatal injury, and property damage only) and each group was systematically sampled. Truck involvements were further stratified on the basis of two major vehicle types: single units and truck combinations.

To explore the unknown area of accident and incident occurrence for which no owners' reports were on file with the State, approximately 14,000 license plate numbers, equally divided between passenger cars and trucks, were selected for mail interview from vehicle registration lists.

Passenger car license plate numbers were selected randomly with no consideration given to size or weight of vehicle; truck license plate numbers were stratified on the basis of light, medium, and heavy registered weights with different sampling rates applicable thereto. (In Illinois, a license plate remains with the owner and may be transferred to another vehicle in the event a vehicle is replaced.) The 14,000 vehicle owners thus selected were requested to enumerate their total accident and incident experience for 1958 involving the vehicle or vehicles bearing the designated license plate number.

Obviously, because owners selected from vehicle registration lists were requested to give total accident and incident experience, such events reported by owners had to be checked against the official accident records of the State to eliminate happenings that had a chance of being selected in samples of officially reported accidents. Accordingly, those events reported by owners in response to the mailed questionnaire for which a record could be found in the State's files were dropped from the study. The remaining unmatched groups of accidents and incidents were processed as "unreported" events. Details concerning sampling procedures, rates of return, data collection and processing methods have been described at considerable length in a previous report (1). In the aggregate the study produced 7,184 sample cases of passenger cars and trucks involved in an accident or other mishap.

Frequent mention is made throughout the paper of the cost of passenger car accidents as opposed to the cost of truck accidents. Although the passenger car and truck phases of the study were conducted concurrently, they were in effect two separate surveys. This approach was used because the two classes of vehicles represented different universes, not only from the standpoint of numbers of vehicles registered and frequencies of accidents, but also from the consideration of vehicle and vehicle-use characteristics.

DEFINITIONS

In general, the terms used conform with definitions given in "Uniform Definitions of Motor Vehicle Accidents," adopted by the National Conference on Uniform Traffic Accident Statistics. Some of the commonly used terms are defined:

Motor-Vehicle Traffic Accident. —Any accident occurring on a trafficway (street, road, highway), resulting in death, injury or property damage, and involving a motor vehicle in motion.

Motor-Vehicle Nontraffic Accident. —Any accident involving a motor vehicle in motion which occurs entirely on private property or in any place other than a trafficway, and results in death, injury, or property damage.

Motor-Vehicle Traffic Incident. —Any incident involving a motor vehicle not in motion which occurs on a trafficway and results in death, injury, or property damage.

Motor-Vehicle Nontraffic Incident. —Any incident involving a motor vehicle not in motion which occurs entirely on private property or in any other place that is not a trafficway, and results in death, injury, or property damage.

Involvement. —A vehicle involved in an accident is defined as an involvement. Because the sampling unit for the study was a license plate number of a vehicle involved in an accident, the cost data developed were the accumulation of costs surrounding selected vehicles involved in accidents or other mishaps. The costs thus determined were factored on the basis of sample selection rates with appropriate adjustments for incompleted cases. The term "involvement" is a useful expression in describing the components of an accident; i. e., size and weight of vehicle involved, age of vehicle, age and sex of driver, etc.

Accidents as such were not sampled because of procedural difficulties inherent in sampling single vehicle accidents and multiple vehicle accidents, and in tracing the ownership of vehicles involved in multivehicular accidents.

SCOPE OF STUDY

Inasmuch as the primary purpose for undertaking studies of this type is to develop accident cost data, a discussion of cost concepts is necessary. The theory on which such studies are based, as developed by the Highway Research Board Committee on Economic Costs of Motor Vehicle Accidents over a decade ago (1949), may be stated briefly as those costs represented by the money value of damages and losses to persons and property. Money spent by persons involved in accidents may or may not be the same as the money value of damages or losses. Damage to property may not be repaired and losses may not be compensated, but such costs are included in the money value concept as they will be realized in the form of depreciated value or decreased earnings. Payment for damages and losses is not always made by the vehicle owner or person injured; the driver or owner of another vehicle may pay the costs; insurance companies may reimburse in full or in part for damages; hospitals, doctors, and others may furnish services and not be compensated fully; and courts may award damages in excess of or less than actual costs. No attempt is made to trace the transfer of money or to determine actual amounts of money spent, except to the extent that such expenditures measure the money value of damages or losses to persons and property.

Direct costs are composed of the money value of damage to property, ambulance use, hospital and treatment costs, doctor and dentist services, loss of use of vehicle costs, value of work time lost, legal and court fees, damage awards and settlements, and other miscellaneous items. The valuation of these direct costs was made on the basis of information supplied by persons whose vehicles were involved in accidents, by persons who were injured in accidents, relatives of injured persons, doctors and dentists, insurance agents and brokers, attorneys, police, and others. A detailed explanation of the various cost elements considered in the study is given in a previous publication (1).

Such items as loss of future earnings of persons killed or permanently injured in accidents are excluded from the direct cost phase of the study, except to the extent that damage awards or settlements made either in or out of court may compensate for such losses. Also, expenditures made by public and private agencies in the interest of accident prevention or to mitigate the economic burden of accidents, and the overhead cost of automobile and certain other types of insurance are not a part of the direct cost phase of this study.

TABLE 1

ACCIDENT AND INCIDENT DIRECT COSTS, ILLINOIS, 1958

Type of Event	Cost ($)	
	Passenger Cars	Trucks
Traffic accident	258,770,000	18,081,000
Nontraffic accident	8,514,000	1,951,000
Traffic incident	15,321,000	610,000
Nontraffic incident	8,064,000	2,174,000
Total	290,669,000	22,816,000

Table 1 gives an overall perspective of total direct costs of accidents and incidents occurring in Illinois during 1958 as determined in the study.

On adding the out-of-state accidents and incidents of Illinois vehicles to the data in Table 1, total direct costs would be as follows: passenger cars, $309.5 million; and trucks, $29.3 million. The costs thus determined in the study amounted to $1/3 billion, or an average of $928,000 per day.

To avoid possible misconceptions, the reader should bear in mind that the data do not include the cost of all accidents occuring on Illinois highways. Included in the study are direct costs to persons and property associated with accidents or incidents involving privately owned Illinois-registered passenger cars and trucks. Specifically, the data are representative of the costs incurred by owners and occupants of Illinois passenger cars and trucks, and by pedestrians and other nonmotorists involved in such accidents. Excluded from the study are direct costs to persons and property associated with accidents involving the following:

1. Out-of-state registered motor vehicles of all types.
2. Publicly owned motor vehicles of all types.
3. Illinois-registered buses, motorcycles, motorized bicycles and scooters, and any other conveyance classified as a motor vehicle.

Costs incurred by owners and occupants of the three categories of vehicles just listed are excluded, even though such vehicles may have been involved in an accident with a privately owned Illinois passenger car or truck.

Although the study encompassed total accident and incident experience of Illinois passenger car and truck owners, regardless of whether the events occurred on or off the highway or in or out of State, subsequent discussion in this paper is restricted to traffic accidents occurring on Illinois highways and streets.

REPORTED AND UNREPORTED ACCIDENT INVOLVEMENTS

Table 2 gives the relationship of reported and unreported accident involvements and the corresponding costs. An unreported involvement refers to an event for which no record of an owner's report could be found in the accident report files maintained by the Illinois Division of Highways. Several factors could account for this, but the principal one would be that property damage costs were less than the legal reporting minimum. If the accident was of the "reportable" category and no record could be found, one of the following conditions might apply: the owner may have reported the accident to local authorities but not to the State; the owner may have failed to report the happening to any governmental authority; or through error the accident report may have been overlooked in the search of the State's accident files. Every effort was made to prevent the last possibility through a careful review of all reportable accidents.

Approximately 1.3 million Illinois passenger cars of private ownership were involved in traffic accidents on Illinois roads and streets during 1958. Direct costs of these accidents amounted to $258.8 million or an average of $196 per passenger car involved. Totals include all degrees of severity—fatal injury, nonfatal injury, and property damage only. Three-fourths of these events were not officially reported to the Illinois Division of Highways, and in the aggregate they accounted for over two-fifths of the total cost. The mean value for unreported passenger car involvements was $110 and the median value was $50.

Approximately 128,000 trucks were involved in accidents costing $18.1 million, or an average of $141 for each event. Unreported involvements accounted for four-fifths

TABLE 2

REPORTED AND UNREPORTED TRAFFIC ACCIDENTS AND THEIR DIRECT COSTS, ILLINOIS, 1958

Vehicle Type	Involvement	Number of Vehicles Involved in Accidents	Percent of Total	Total Direct Cost ($)	Percent of Total	Cost per Involvement ($)	Involvements per 10 Million Vehicle-Miles[1]	Cost per Vehicle-Mile ($)
Passenger car	Reported	317,100	24.1	149,198,000	57.7	471	119	0.0056
	Unreported	1,000,600	75.9	109,572,000	42.3	110	374	0.0041
	Total	1,317,700	100.0	258,770,000	100.0	196	493	0.0097
Truck:								
Single-unit	Reported	20,600	18.8	5,818,000	43.3	282	50	0.0014
	Unreported	89,100	81.2	7,607,000	56.7	85	216	0.0019
	Total	109,700	100.0	13,425,000	100.0	122	266	0.0033
Combination	Reported	4,500	24.5	2,367,000	50.8	526	54	0.0028
	Unreported	13,900	75.5	2,289,000	49.2	165	167	0.0028
	Total	18,400	100.0	4,656,000	100.0	253	221	0.0056
All	Reported	25,100	19.6	8,185,000	45.3	326	51	0.0016
	Unreported	103,000	80.4	9,896,000	54.7	96	207	0.0020
	Total	128,100	100.0	18,081,000	100.0	141	258	0.0036

[1] Travel of Illinois-registered vehicles: passenger cars, 26,748,000,000 vehicle-miles; single-unit trucks, 4,124,000,000 vehicle-miles; and truck combinations, 832,000,000 vehicle-miles.

of the number and over one-half of the total cost. The mean and median values for unreported truck involvements were $96 and $20, respectively.

It should not be construed that all unreported involvements in which costs exceeded $100 were in violation of the reporting law. The cost values include elements that do not enter into the legal reporting requirement of damage to property. For example, such elements as "time lost from work" or "loss of use of vehicle" are included when applicable in the cost values in Table 2.

The cost distribution of reported and unreported involvements is shown in Figure 1. It is clearly evident that a very high proportion of unreported involvements were relatively minor events. Of these unreported events, 92 percent cost less than $300. The same percentage for officially reported involvements indicated costs of less than $1,000.

ACCIDENT EXPOSURE

Accident involvement rates for passenger cars calculated on the basis of 10 million vehicle-miles of travel (Table 2) were nearly twice those for trucks, and the cost of accidents per vehicle-mile of travel approached $0.01 for passenger cars or 2.7 times the rate found for trucks. When trucks are considered on the basis of single units and combinations, the data show a lower involvement rate for combinations but a higher cost per vehicle-mile. This relationship could logically be expected because operators of truck combinations would in most cases be more experienced and skillful drivers. Vehicle and vehicle-use characteristics should also be considered in such a comparison. On the other hand, when the heavy units are involved in accidents, they tend to be more severe and costly, particularly when cargo damage is involved. Among the single-unit trucks, panels and pickups accounted for 55 percent of the vehicles in use, 56 percent of the travel, and 53 percent of the vehicles involved in accidents. These two truck types are often used for personal transportation, and in many respects their operation is similar to that of passenger cars.

The number of privately owned Illinois vehicles registered and in use during 1958 and their average annual in-State travel per vehicle are given in Table 3 (2).

In relating vehicles in use to the number of vehicles involved in accidents, it was found that the probability of a passenger car being involved in a traffic accident was once in 26 months; for single-unit trucks, once in 39 months; and truck combinations, once in 15 months. Exposure to accidents, based on average annual travel, was three times greater for truck combinations as compared to single-unit trucks, and nearly four times that of passenger cars.

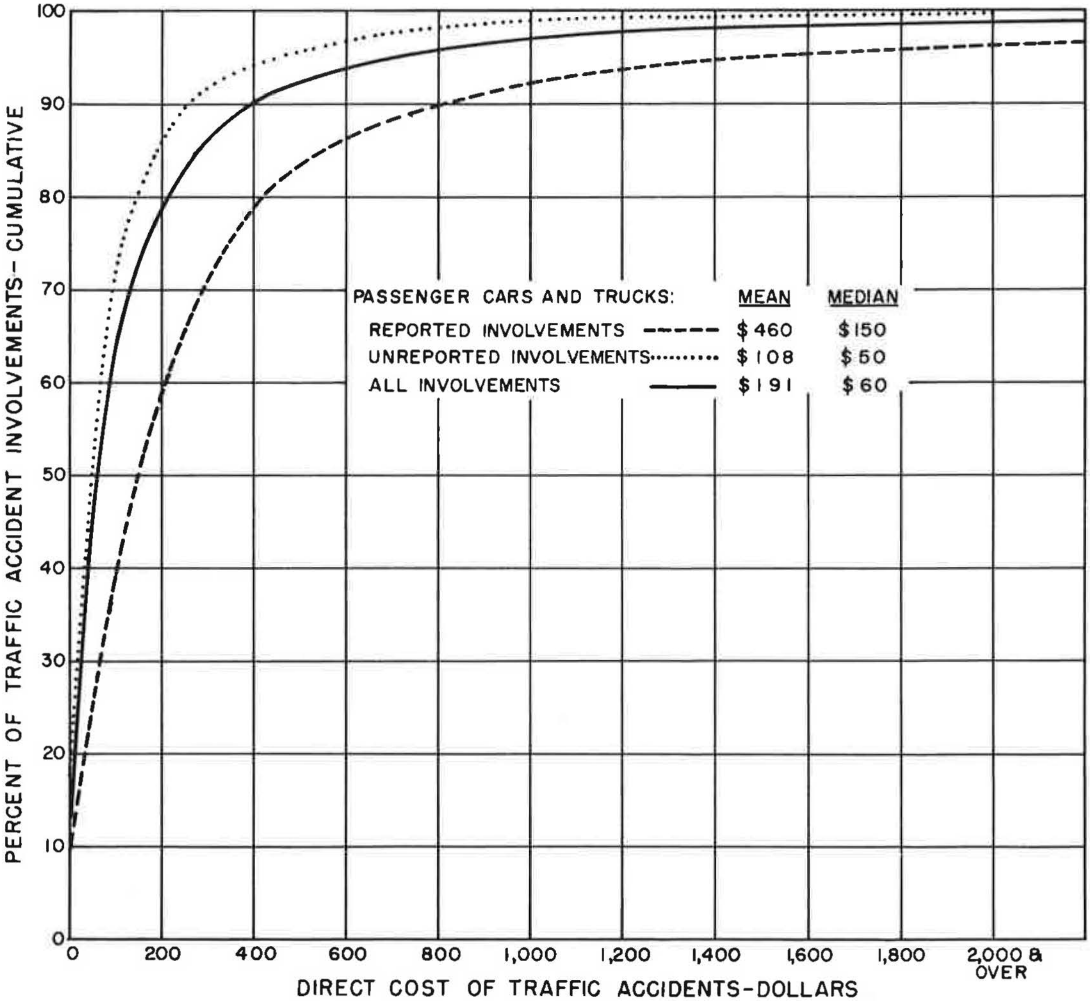

Figure 1. Cumulative percentage distribution of reported and unreported traffic accident involvements vs direct cost.

TABLE 3

VEHICLE REGISTRATION AND AVERAGE ANNUAL IN-STATE TRAVEL, ILLINOIS, 1958

Type of Vehicle	No. of Vehicles in Use	Average Annual Travel per Vehicle (mi)
Passenger car	2,876,000	9,300
Single-unit truck		
Panel or pickup	194,400	11,950
Other 2-axle trucks	153,800	10,900
3-axle truck	6,600	19,140
Total	354,800	11,620
Truck combination:		
3-axle tractor semitrailer	12,000	24,850
Other truck combinations	11,300	47,340
Total	23,300	35,740

TABLE 4

NUMBER OF TRAFFIC ACCIDENT INVOLVEMENTS IN ILLINOIS INVOLVING VEHICLES OF ILLINOIS REGISTRY, 1958, CLASSIFIED BY SEVERITY OF ACCIDENT AND COST ELEMENTS INCURRED

Cost Element	Passenger Car Accidents				Truck Accidents			
	Fatal Injury	Nonfatal Injury	Property Damage Only	Total	Fatal Injury	Nonfatal Injury	Property Damage Only	Total
Number of involvements with:								
Damage to vehicle	1,391	142,824	990,672	1,134,887	189	6,001	66,639	72,829
Damage to property in vehicle	75	2,708	12,929	15,712	44	384	2,158	2,586
Damage to objects struck by vehicle	85	2,067	17,252	19,404	18	195	3,295	3,508
Miscellaneous property damage	28	3,450	5,263	8,741	27	137	1,488	1,652
One or more property damage cost elements	1,391	143,259	1,000,539	1,145,189	193	6,087	68,539	74,819
Ambulance costs	625	7,224	--	7,849	55	761	--	816
Doctor and dentist fees	903	84,104	--	85,007	105	2,827	--	2,932
Hospital and treatment costs	940	64,188	--	65,128	93	2,089	--	2,182
Miscellaneous injury costs	334	6,885	--	7,219	27	261	--	288
One or more injury cost elements	1,067	94,703	--	95,770	119	2,967	--	3,086
Loss of use of vehicle costs	43	6,473	23,037	29,553	55	780	5,796	6,631
Value of time lost from work	653	77,368	22,817	100,838	94	2,428	3,612	6,134
Legal and court costs	734	37,296	10,108	48,138	90	1,342	644	2,076
Damage awards in excess of known costs	705	48,810	9,227	58,742	109	1,130	96	1,335
Summary of number of involvements:								
With one or more direct cost elements	1,532	155,057	1,003,041	1,159,630	232	6,718	69,882	76,832
With no costs incurred	28	9,534	148,466	158,028	5	2,955	48,293	51,253
Total	1,560	164,591	1,151,507	1,317,658	237	9,673	118,175	128,085

DIRECT COST ELEMENTS

The cost elements that make up the total cost figures in Table 2 are given in considerable detail in Tables 4, 5, and 6. Table 7 shows the relative number and cost of each of the three severity classes of accidents.

It is evident that fatal injury involvements accounted for a small proportion of the number and cost of accidents. Also, nonfatal injury accidents involving passenger cars represented a considerably higher proportion of the total costs than similar events involving trucks. Injuries to passengers would largely account for this difference. Trucks normally have only one occupant, the driver.

As mentioned earlier, the cost data do not include values for "loss of future earnings" of persons killed or permanently injured, except to the extent that awards or

TABLE 5

DIRECT COST OF TRAFFIC ACCIDENTS IN ILLINOIS INVOLVING VEHICLES OF ILLINOIS REGISTRY, 1958

Cost Element	Direct Cost of Passenger Car Accidents ($)				Direct Cost of Truck Accidents ($)			
	Fatal Injury	Nonfatal Injury	Property Damage Only	Total	Fatal Injury	Nonfatal Injury	Property Damage Only	Total
Property damage:								
Damage to vehicle	1,196,385	41,368,456	109,795,996	152,360,837	270,836	2,191,845	7,642,290	10,104,971
Damage to property in vehicle	8,225	160,670	645,458	814,353	38,222	80,001	171,903	290,126
Damage to objects struck by vehicle	23,218	406,368	1,688,634	2,118,220	2,368	164,805	704,232	871,405
Miscellaneous property damage	846	69,548	142,302	212,696	1,761	6,095	17,267	25,123
Subtotal	1,228,674	42,005,042	112,272,390	155,506,106	313,187	2,442,746	8,535,692	11,291,625
Treatment of injuries:								
Ambulance costs	19,317	173,300	--	192,617	1,495	17,234	--	18,729
Doctor and dentist fees	354,709	10,304,366	--	10,659,075	25,325	615,569	--	640,894
Hospital and treatment costs	686,858	9,415,140	--	10,101,998	32,178	339,578	--	371,756
Miscellaneous injury costs	29,845	318,974	--	348,819	1,246	11,395	--	12,641
Subtotal	1,090,729	20,211,780	--	21,302,509	60,244	983,776	--	1,044,020
Loss of use of vehicle costs	10,152	666,718	1,013,342	1,690,212	61,697	236,266	1,446,990	1,744,953
Value of time lost from work	636,239	17,274,842	846,022	18,757,103	63,436	1,688,287	129,008	1,880,731
Legal and court costs	1,557,909	23,301,020	1,091,790	25,950,719	146,509	542,818	28,056	717,383
Damage awards in excess of known costs	3,372,203	31,655,984	534,784	36,562,971	570,297	830,934	1,301	1,402,532
Total Cost	7,895,906	135,115,386	115,758,328	258,769,620	1,215,370	6,724,827	10,141,047	18,081,244

TABLE 6

MEAN VALUES FOR COST ELEMENTS FROM ILLINOIS TRAFFIC ACCIDENTS INVOLVING VEHICLES OF ILLINOIS REGISTRY

Cost Element	Mean Cost Value for Each Element of Cost ($)							
	Passenger Car Accidents				Truck Accidents			
	Fatal Injury	Nonfatal Injury	Property Damage Only	All	Fatal Injury	Nonfatal Injury	Property Damage Only	All
Property damage:								
To vehicle	860	290	111	134	1,433	365	115	139
To property in vehicle	110	59	50	52	869	208	80	112
To objects struck by vehicle	273	197	98	109	132	845	214	248
Miscellaneous	30	20	27	24	65	44	12	15
Mean cost value[1]	883	293	112	136	1,623	401	125	151
Treatment of injuries:								
Ambulance costs	31	24	--	25	27	23	--	23
Doctor and dentist fees	393	123	--	125	241	218	--	219
Hospital and treatment costs	731	147	--	155	346	163	--	170
Miscellaneous injury costs	89	46	--	48	46	44	--	44
Mean cost value[2]	1,022	213	--	222	506	332	--	338
Loss of use of vehicle costs	236	103	44	57	1,122	303	250	263
Value of time lost from work	974	223	37	186	675	695	36	307
Legal and court costs	2,122	625	108	539	1,628	404	44	346
Damages awarded in excess of known costs	4,783	649	58	605	5,232	735	14	1,051
Mean cost value[3]	5,154	871	115	223	5,239	1,001	145	235

[1]For involvements in which one or more property damage cost elements were incurred.
[2]For involvements in which one or more injury cost elements were incurred.
[3]For involvements in which one or more cost elements were incurred.

settlements may measure this loss. Awards or settlements are based primarily on the "fault" concept, and thus the victim or survivors may not have recourse to recover losses due to death or injury. This situation would apply particularly to single vehicle accidents.

Passenger car and truck involvements that occasioned no costs (or less than $5.00) were quite numerous as shown in Table 4. Table 8 gives a comparison of such events.

The finding that approximately 2 percent of the fatal injury involvements were of the no-cost category might appear unreasonably high at the outset. A typical case would be a passenger car or truck colliding with a pedestrian. Under the conditions that the pedestrian was at fault, that the victim died instantly, that the vehicle was not damaged, that no time was lost from work by the vehicle owner or driver, and that a police vehicle was used to remove the victim from the scene, no costs would be assessed for this accident within the scope of the direct cost phase of the study. Funeral costs are not considered as an element of cost in connection with a motor-vehicle accident. Such costs are inevitable; an accident merely fixes the time when they are incurred.

Another example of a no-cost involvement applies to a multiple vehicle accident. In a two-car collision, one vehicle might be damaged and the bumper of the other vehicle

TABLE 7

RELATIVE NUMBER AND COST OF ACCIDENT TYPES

Type of Vehicle	Type of Accident	Percent of Vehicles Involved	Percent of Cost
Passenger cars	Fatal injury	0.1	3.1
	Nonfatal injury	12.5	52.2
	Property damage only	87.4	44.7
	Total	100.0	100.0
Trucks	Fatal injury	0.2	6.7
	Nonfatal injury	7.6	37.2
	Property damage only	92.2	56.1
	Total	100.0	100.0

absorbs the shock. Under the sampling procedure used in the study, either vehicle or both might be selected. A large proportion of the no-cost involvements were of the unreported accident category (Fig. 1). Trucks, in particular, were involved in a number of nonfatal injury and property damage only accidents in which no costs were incurred by the owner or occupants of the vehicle selected. This situation is explained partially by the fact that most truck accidents involved collisions with passenger cars. Conditions acting in favor of trucks from the cost standpoint were the lower occupancy rate (persons per vehicle) and vehicle capability to withstand impact. The severity classification is determined by the accident and not by what takes place in one of the vehicles involved.

TABLE 8

COMPARISON OF PASSENGER CAR AND TRUCK INVOLVEMENTS OF NO COST

Type of Accident	No-Cost Involvements (% of total)	
	Passenger Cars	Trucks
Fatal injury	1.8	2.1
Nonfatal injury	5.7	30.5
Property damage only	12.9	40.9
Total	12.0	40.0

In a study based on sampling techniques, it is obvious that the greater the detail provided in tabular form the greater the chance of exceeding the built-in limitations of sample size. As an indication of the strength of the data in Tables 4, 5, and 6, Table 9 gives a comparison of sample sizes and expanded totals.

The total cost figure of $258.8 million for passenger car accidents (Table 5) is based on 3,383 completed sample cases, and the amount of $18.1 million for trucks is based on 3,026 cases. The ratios of sample cases to the expanded number of involvements do not reflect the sampling rates as originally selected. As mentioned earlier, two sampling sources were used (official accident reports and registration lists) and different sampling rates applied. A full description of sampling procedures is given elsewhere (1).

Cost data in Table 5 are further illustrated in Figures 2 and 3. The top set of bars in Figure 2, arranged in order of magnitude, show the distribution of the accident dollar. Property damage accounted for 60 percent (or $0.60 of the accident dollar) of the total cost of all passenger car traffic accidents, and 62 percent in the case of trucks (Fig. 3). Treatment of injuries, legal and court fees, and excess damage awards and settlements accounted for a larger proportion of the total cost of passenger car accidents than for trucks. On the other hand, costs related to "time loss" and "loss of use of vehicle" represented a larger proportion

TABLE 9

COMPARISON OF SAMPLE SIZE AND EXPANDED NUMBER OF INVOLVEMENTS

Type of Vehicle	Type of Accident	Number of Involvements	Number of Sample Cases
Passenger car	Fatal injury	1,560	332
	Nonfatal injury	164,591	1,761
	Property damage only	1,151,507	1,290
	Total	1,317,658	3,383
Truck	Fatal injury	237	200
	Nonfatal injury	9,673	1,270
	Property damage only	118,175	1,556
	Total	128,085	3,026

of the total cost for trucks than for passenger cars. The cost element "loss of use of vehicle" is not too significant in the case of passenger car owners because in most cases the use of the vehicle is not essential in earning a livelihood. The latter criterion is used in determining such costs.

In the case of truck owners, and particularly fleet operators, no "loss of use of vehicle" costs are included when standby equipment is available to replace the damaged vehicle. Only a portion of the cost of maintaining standby equipment could properly be charged to motor vehicle accidents as standby vehicles are brought into service for purposes other than accidents; i.e., peak operations, maintenance of equipment, etc. The pro rata share of the overhead cost of maintaining standby equipment to be charged to accidents would be included in the "indirect cost" phase of accident cost studies.

Damage awards and settlements in excess of known costs represented the greatest portion of the accident dollar for both passenger car and truck fatal injury accidents. In determining excess awards and settlements, compensation received by each injured person or survivor and by each vehicle owner was considered on an individual basis. Payments received by the injured person or vehicle owner from his own insurance company were not considered as awards or settlements, because such payments would simply represent a "return of capital." Damage awards and settlements include payments made by the other party, presumably the one found liable. Lump-sum payments under workmen's compensation were included also.

In the case of an injured person, known costs of ambulance use, hospitalization, doctor and dentist fees, time loss, legal fees, etc., were deducted from the award or settlement, and any surplus represented reimbursement for costs that could not be classified. A vehicle owner may also receive a settlement for damage to his vehicle, other property, time loss, loss of use of vehicle, etc., and the settlement may exceed the known costs. The surplus again was treated as an unclassified cost.

In the study procedure, awards and out-of-court settlements were recorded in total, regardless of whether the amounts were less than, equal to, or greater than the actual money value of damages and losses. Obviously, the total amount of an award or settlement could not be added to the previously determined money value of damages and losses because this procedure would duplicate all or part of the costs. For this reason, the amount of damage awards and settlements was ascertained, but only that portion in excess of the value of damages and losses was included in the cost of accidents. Such excess awards or settlements could represent compensation for pain and suffering, loss of future earnings of persons killed or permanently injured, future medical expenses, and other indeterminable costs.

Mean values for each element of cost incurred in passenger car and truck accidents (Table 6) are heavily influenced by high-cost accidents. Median values for each cost element would be substantially lower than the values reported. The positive skewness of the cost curves for each of the severity classes of accidents is shown later.

The final entry in Table 6 gives the average costs of accident involvements in which one or more cost elements were incurred. Truck involvements for each severity class averaged higher costs than was the case for passenger cars. Costs sustained in traffic accidents of all severity classes averaged $223 for passenger car involvements and $235 for trucks. After including involvements in which no costs were incurred (Table 4), the averages drop to $196 and $141, respectively.

SKEWNESS OF COST DISTRIBUTION

The difficulties of sampling the "universe" of traffic accident involvements for the purpose of determining cost data are apparent after viewing the cumulative percentage curves in Figures 4 through 7. Findings of the study show a range of costs per vehicle involvement from zero (or less than $5) to $136,800. Figure 4

Figure 2. Percentage distribution of direct costs of passenger car traffic accidents, by cost element.

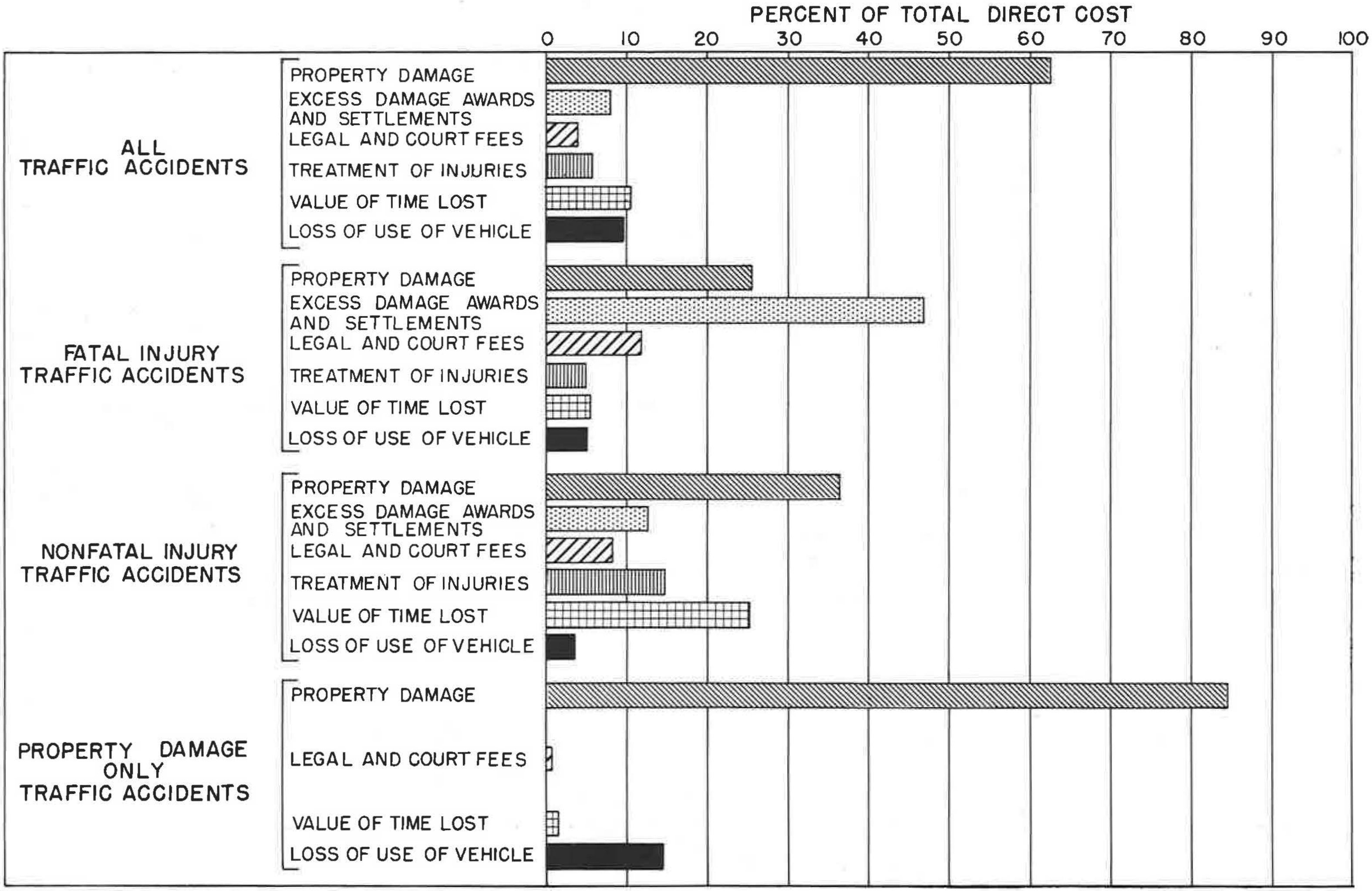

Figure 3. Percentage distribution of direct costs of truck traffic accidents, by cost element.

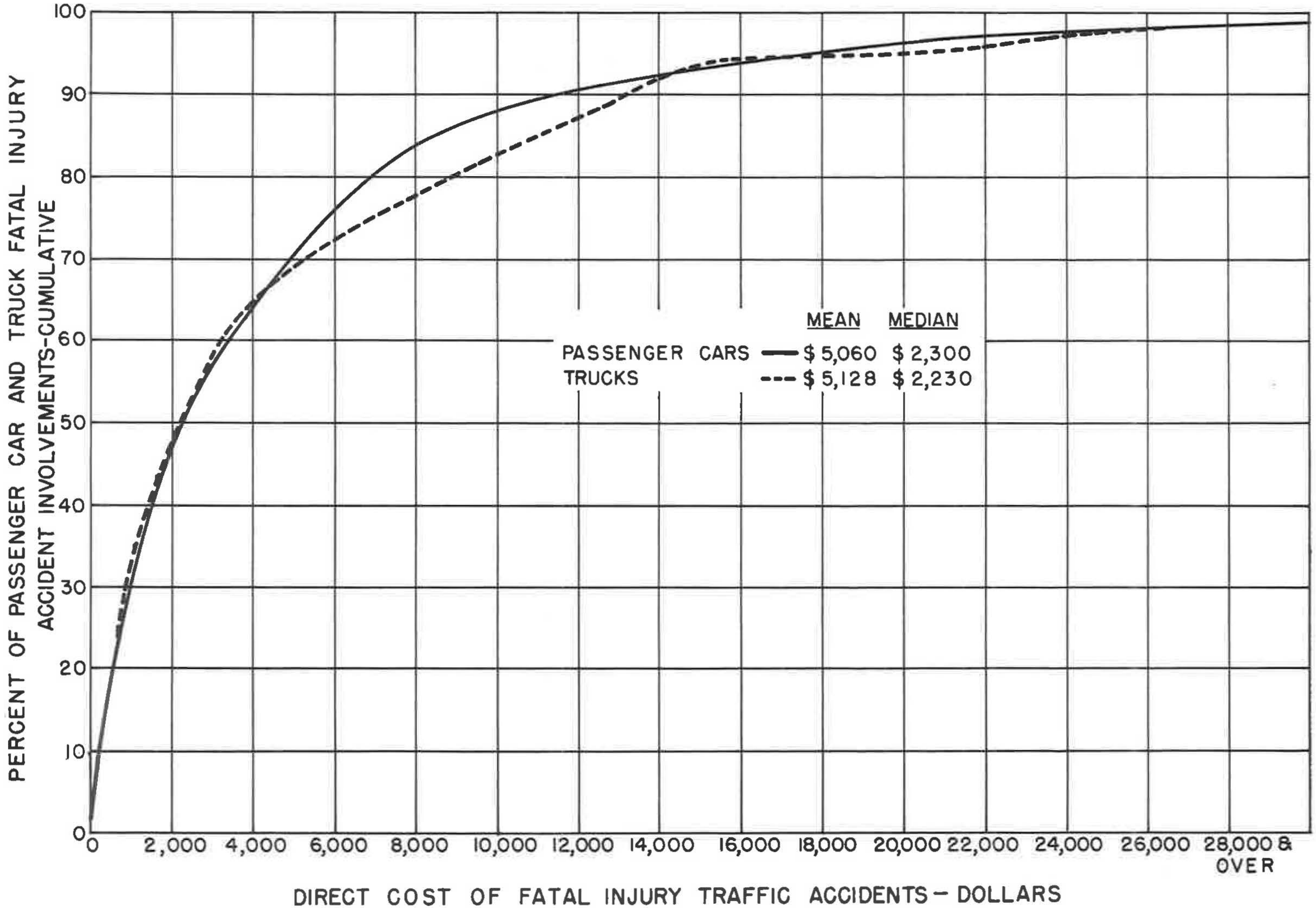

Figure 4. Cumulative percentage distribution of passenger car and truck fatal injury traffic accident involvements vs direct cost.

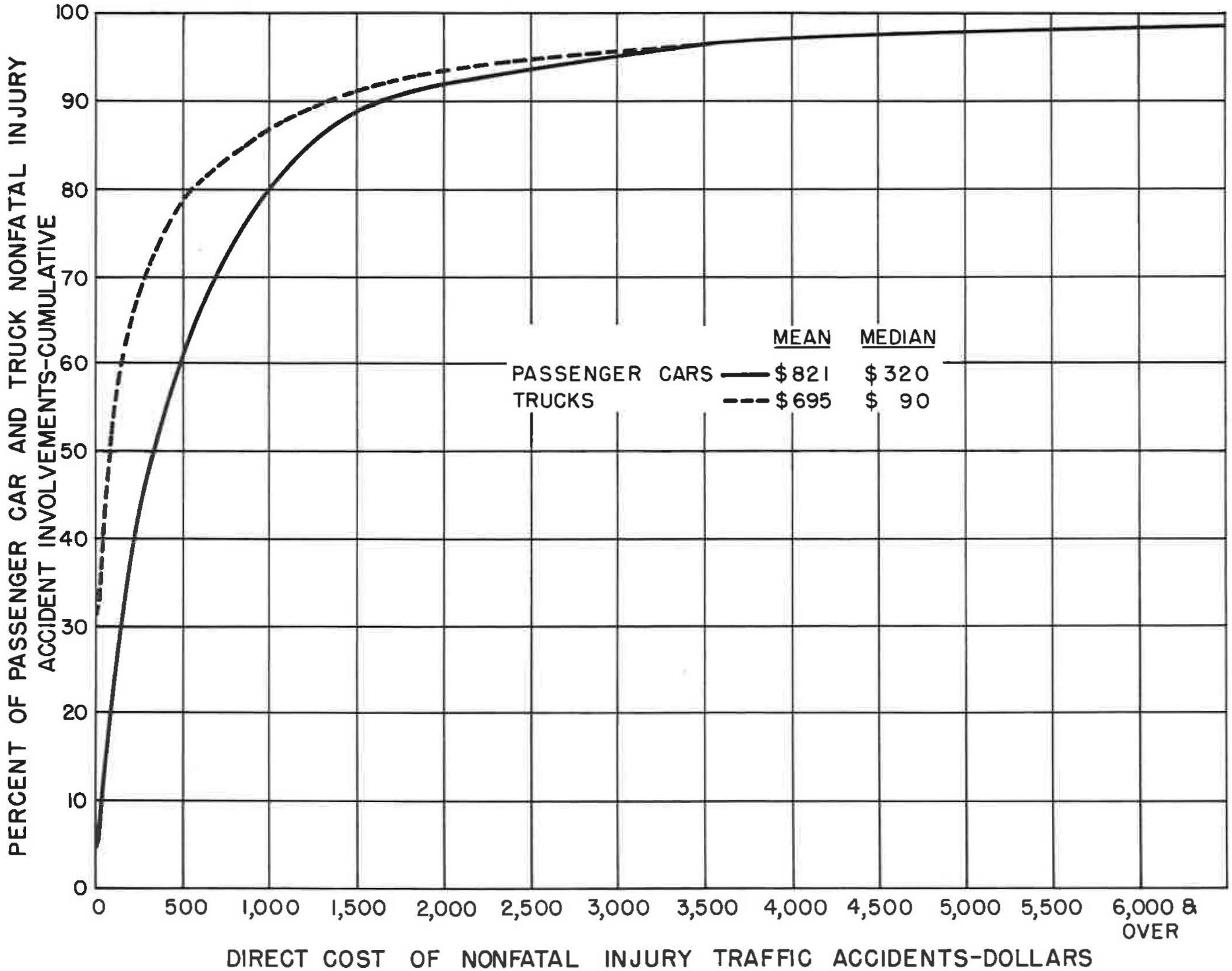

Figure 5. Cumulative percentage distribution of passenger car and truck nonfatal injury traffic accident involvements vs direct cost.

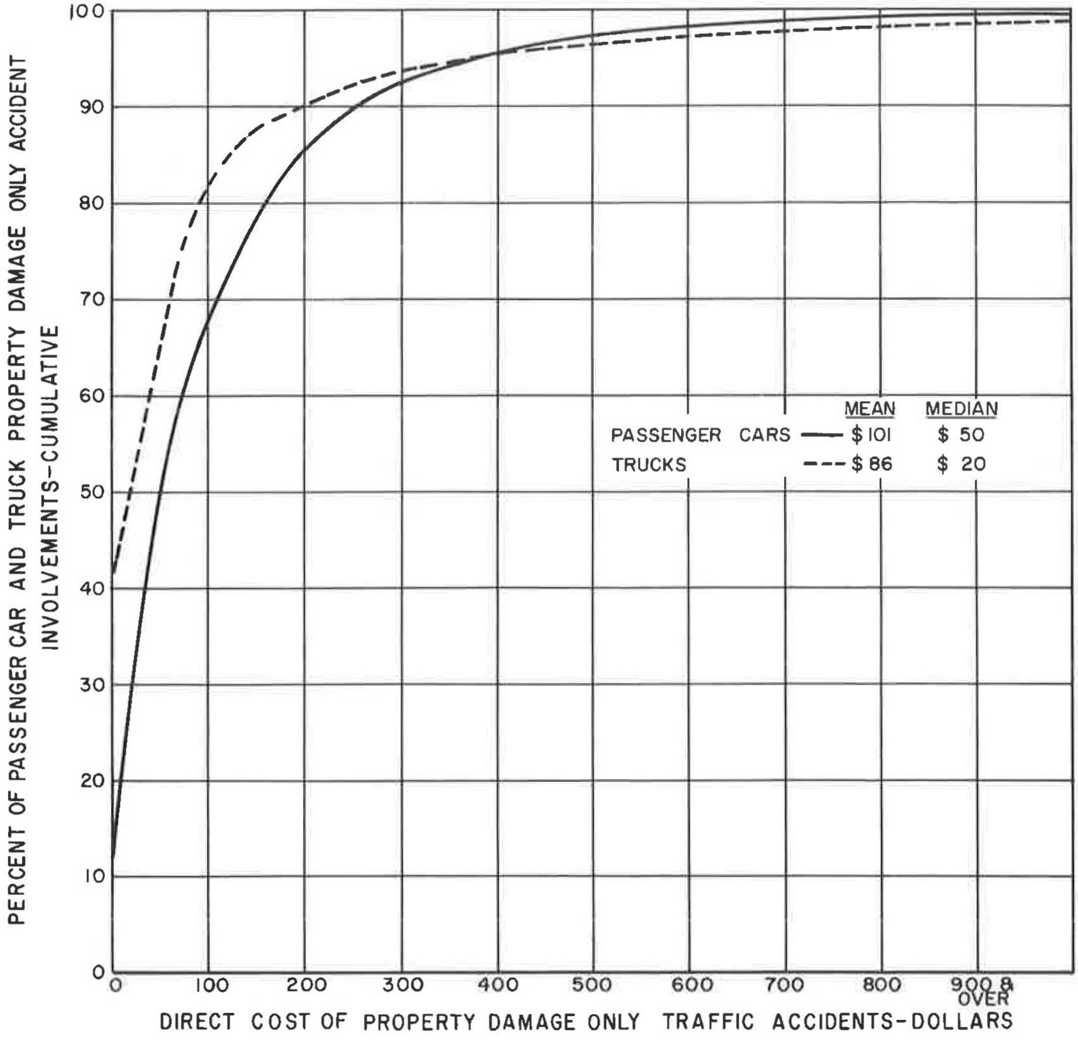

Figure 6. Cumulative percentage distribution of passenger car and truck property damage on only traffic accident involvements vs direct cost.

shows the case in point. Ninety percent of the fatal injury passenger car involvements fell within the cost range of $11,600 or less; a similar percentage for trucks indicated a range of $13,200 or less. The remaining 10 percent of the fatal injury passenger car involvements accounted for 48 percent of the total direct costs of fatal injury accidents. For trucks, the same proportionate group accounted for 45 percent of the total direct costs of fatal injury accidents. The extreme plotting interval in Figure 4 of $28,000 and over was representative of only 1½ percent of the total fatal injury involvements for both passenger cars and trucks, and yet this remote class accounted for nearly 19 percent of the costs of fatal injury passenger car accidents and nearly 12 percent of the total in the case of trucks.

The cumulative percentage curves for nonfatal injury accident involvements are shown in Figure 5. Again, the extreme plotting interval of $6,000 and over was representative of 1½ percent of both passenger car and truck nonfatal injury involvements. This group, however, accounted for 26 percent of the total cost of nonfatal injury passenger car involvements and 22 percent of the total in the case of trucks.

As would be expected, the range in costs of property damage only involvements was less extreme than that for fatal and nonfatal injury involvements. There are exceptional cases though. A heavily damaged passenger car usually results in injury to the driver or a passenger. Trucks, on the other hand, may run off the highway, overturn, and cause excessive damage to vehicle and load, but the driver may escape unscathed. The plotting interval of $900 and over, shown in Figure 6, accounted for 0.5 percent of the passenger car involvements and slightly over 1 percent for trucks. Costs represented by these small groups accounted for 5 percent of the total for passenger cars and 25 percent of the total for trucks.

As a further indication of the extreme cost values found in the study, fatal injury involvements ranged from zero to $136,800 for passenger cars and from zero to $46,200 for trucks. Nonfatal injury involvements ranged from zero to $73,300 for passenger cars and $53,700 for trucks. Property damage only involvements reached a maximum of $1,400 for passenger cars and $30,100 for trucks.

High-cost accident cases found in the Illinois study pointed to the need for further refinement in sample design. The extent of such refinement in sample design depends largely on the data available on tabulating cards in a given State's files of officially reported accidents. Of necessity, the sampling procedures in the past have been adapted to existing records.

Figure 7 shows composite involvement and aggregate cost curves for all severity classes of involvements. The average or mean value for passenger car involvements was $196 and $141 for trucks. The mid-values of medians were considerably less—$60 and $20. The cost interval of $2,000 and over, plotted at the extreme right of Figure 7, represents only 1 percent of the total of 1.3 million passenger car involvements and 30 percent of the total direct costs of $258.8 million. An identical comparison for trucks indicates that 1½ percent of the 128,100 involvements fell within the cost interval of $2,000 and over, and this group accounted for 44 percent of the $18.1 million total.

By selecting the cost interval of $10,000 and over, generally the lower limit for bodily injury and liability insurance, it was found that 0.1 percent or 1,339 passenger car involvements out of the total of 1,317,700 fell into this cost interval, and 0.07 percent or 90 truck involvements out of a total of 128,100. These relatively few involvements, however, accounted for 10 and 11 percent, respectively, of the total direct cost of passenger car and truck accidents.

On the basis of the preceding statewide comparison, and assuming that Illinois owners' 1958 experience was typical, the chance of a passenger car owner being involved in an accident in which the costs associated with his vehicle would amount to $10,000 or more would be about 1 in 1,000; for truck owners, the probability of such an event would be about 1 in 1,400. As indicated previously in the paper, 2,876,000 Illinois passenger cars were driven the equivalent of 26.7 billion vehicle-miles in 1958. By referring again to the 1,339 passenger car involvements in which costs equaled or exceeded $10,000, it is evident that the frequency of such an occurrence would be 5.0 involvements per 100 million vehicle-miles, or 1.0 involvement per 20 million vehicle-miles. On this basis, one of approximately 40 passenger car owners in a lifetime of vehicle ownership would be expected to experience an accident in which the costs associated with his vehicle would equal or exceed $10,000.

Figures 8, 9, and 10 show the cost distribution of fatal, nonfatal, and property damage only involvements on the basis of the number of involvements rather than

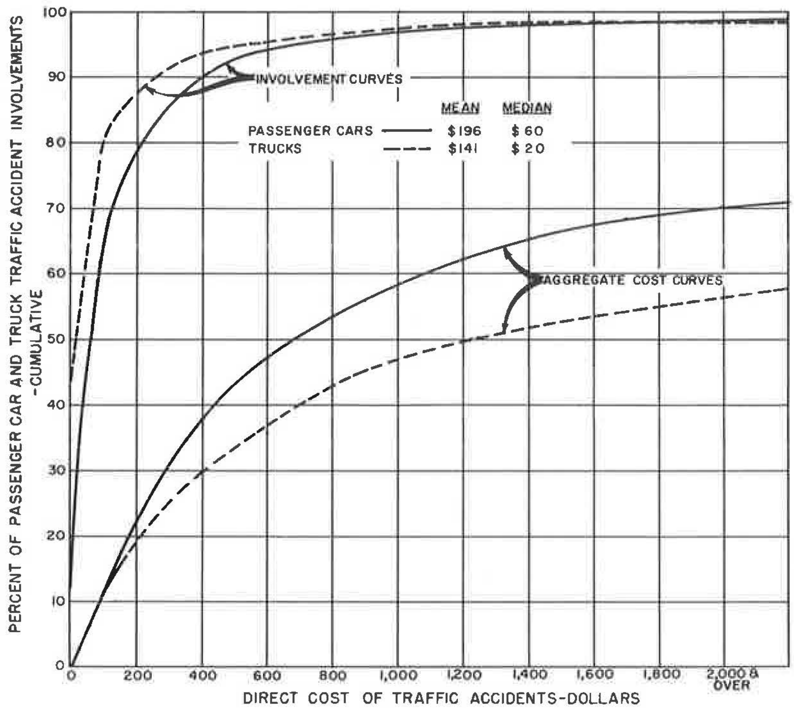

Figure 7. Cumulative percentage distribution of passenger car and truck traffic accident involvements and aggregate costs vs direct cost.

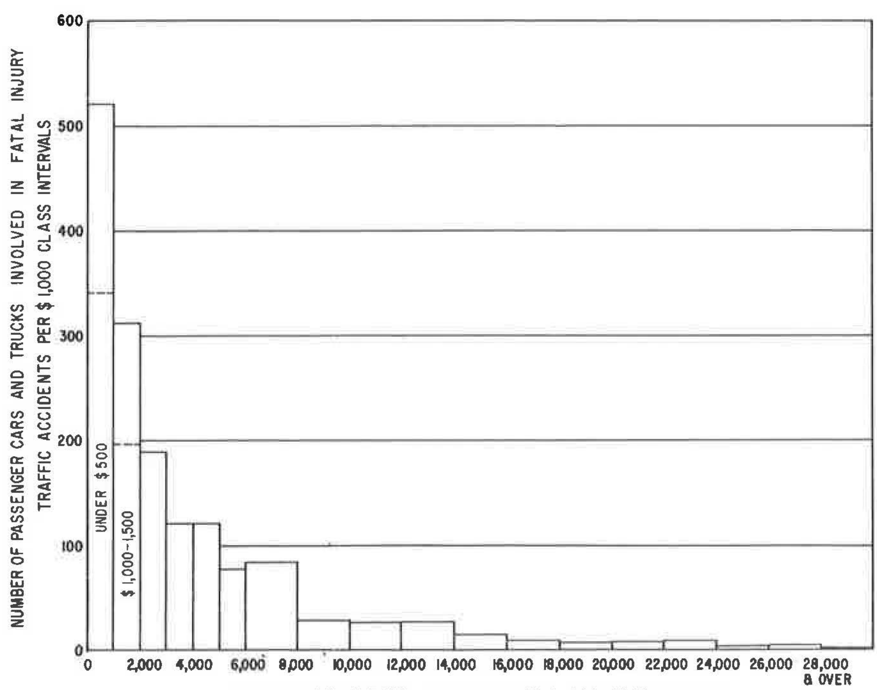

Figure 8. Number of passenger cars and trucks (combined) involved in fatal injury accidents, distributed according to direct costs of involvements.

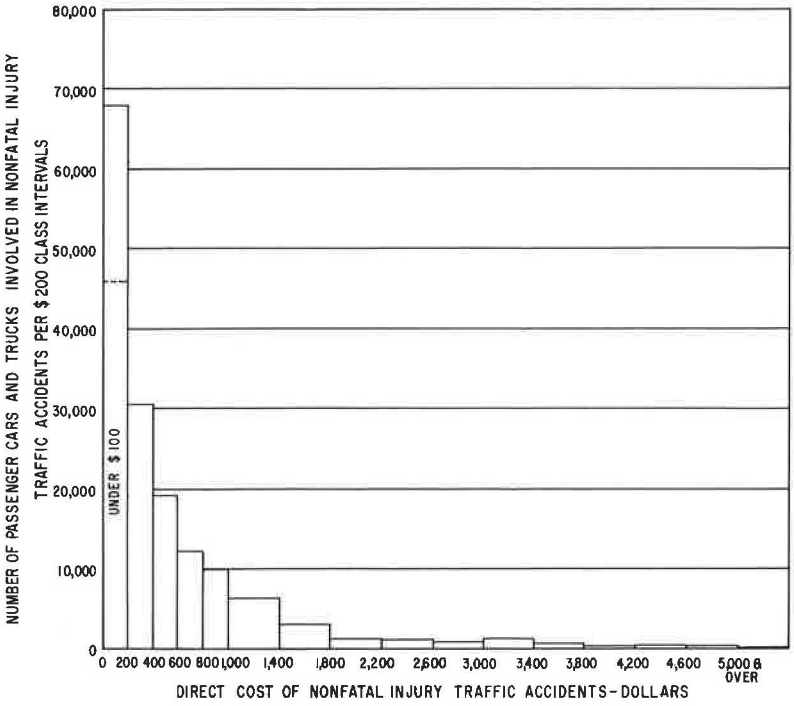

Figure 9. Number of passenger cars and trucks (combined) involved in nonfatal injury traffic accidents, distributed according to direct costs of involvements.

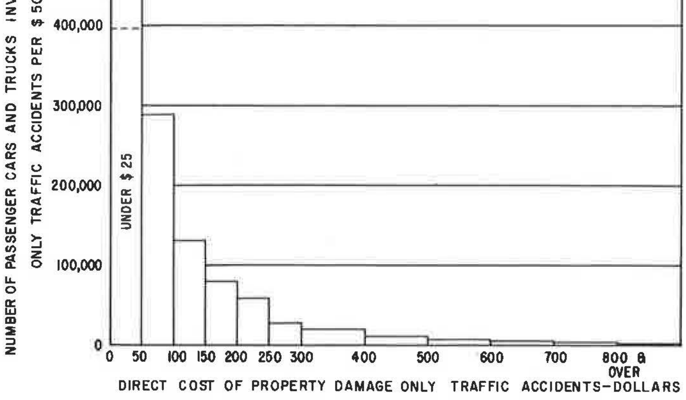

Figure 10. Number of passenger cars and trucks (combined) involved in property damage only traffic accidents, distributed according to direct costs of involvements.

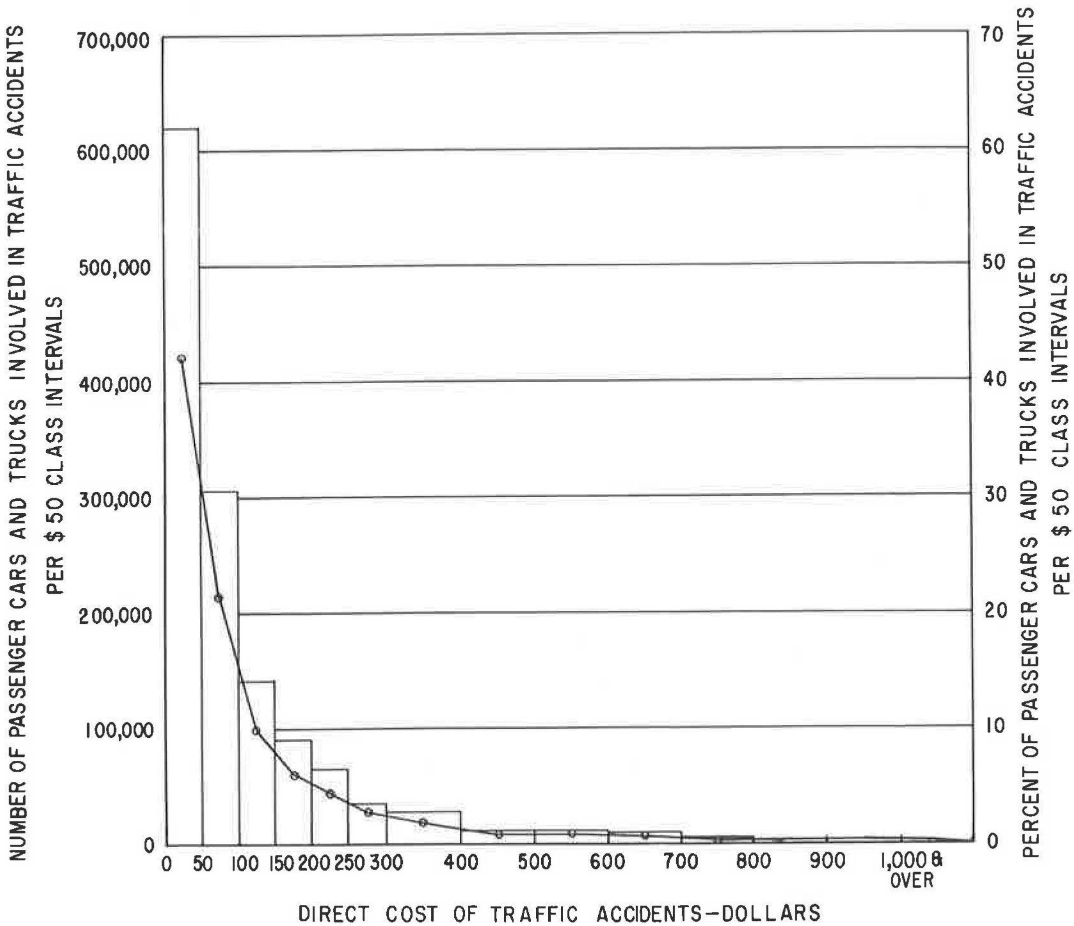

Figure 11. Number and percent of passenger cars and trucks (combined) involved in traffic accidents, distributed according to direct costs of such involvements.

percent of involvements as shown in Figures 4 through 7. The bars in Figures 8, 9, and 10 are representative of the combined number of passenger car and truck involvements. Figure 11 shows a composite distribution for all severity classes of involvements. Many of the characteristics of the cost distribution for each of the severity classes have already been mentioned and need no further emphasis. The bar charts, however, illustrate more forcefully the positive skewness of accident cost curves and emphasize the inherent problems in sampling the universe of accident involvements for the purpose of determining costs. Obviously, the high-cost involvements are subject to considerable sampling variability.

FREQUENCIES AND COSTS OF ACCIDENT INVOLVEMENTS

Related to Accident Location

The usual approach in determining accident exposure is to relate the number of accidents to vehicle-miles of travel. Fortunately, the motor-vehicle use study, conducted by the Illinois Division of Highways during 1958, complements the motor-vehicle accident cost study. The availability of this information is an invaluable aid in relating accidents to highway and vehicle-use characteristics.

Tables 10 and 11 give the basis for determining the frequencies and costs of accident involvements occurring in rural areas and in municipalities. The term "municipality" is used to denote incorporated places regardless of population size. Unincorporated places are included in the rural classification.

Numbers of vehicles involved in traffic accidents and the corresponding costs are not too meaningful unless such events can be related to exposure. Involvement and cost rates per 10 million vehicle-miles of travel are given in Table 12 for passenger cars and major classes of trucks. Passenger car involvement rates ranged from 191 per 10 million vehicle-miles of travel in rural areas to 672 in muncipalities of all population sizes, or a ratio of 1 accident involvement in rural areas for every 3.5 involvements in municipalities. For single-unit trucks, the ratio was 1 to 4.8; for truck combinations, 1 to 6.4.

TABLE 10

NUMBER OF VEHICLES INVOLVED IN AND DIRECT COST OF TRAFFIC ACCIDENTS

Vehicle Type	Rural Areas	Municipalities				
		Under 5,000	5,000-24,999	25,000-125,000	1,000,000 and Over	Total
		(a) Number of Vehicles Involved in Accidents				
Passenger car	190,975	77,463	234,189	302,828	512,203	1,126,683
Single-unit truck:						
Panels and pickups	9,376	7,539	6,663	11,412	22,095	47,709
Other	13,172	2,345	5,806	9,985	19,789	37,925
Total	22,548	9,884	12,469	21,397	41,884	85,634
Truck combinations	3,781	1,049	1,797	3,220	8,506	14,572
Unknown truck type	487	--	102	493	468	1,063
All trucks	26,816	10,933	14,368	25,110	50,858	101,269
		(b) Direct Cost of Accidents ($)				
Passenger car	60,981,882	11,324,294	29,745,538	45,289,744	111,428,162	197,787,738
Single-unit truck:						
Panels and pickups	4,046,099	552,199	507,201	1,025,711	1,494,471	3,579,582
Other	2,991,158	291,468	305,192	832,470	1,309,983	2,739,113
Total	7,037,257	843,667	812,393	1,858,181	2,804,454	6,318,695
Truck combinations	2,059,289	522,112	516,291	347,532	1,211,188	2,597,123
Unknown truck type	9,963	--	3,057	40,528	15,332	58,917
All trucks	9,106,509	1,365,779	1,331,741	2,246,241	4,030,974	8,974,735

TABLE 11

VEHICLE-MILES OF TRAVEL IN ILLINOIS BY VEHICLES OF DIFFERENT TYPES BY LOCATION OF TRAVEL[1]

Vehicle Type	Vehicle-Miles of Travel (×1,000)					
	Rural Areas	Municipalities				
		Under 5,000	5,000-24,999	25,000-125,000	1,000,000 and Over	Total
Passenger car	9,986,084	1,984,221	3,012,843	4,064,738	7,700,420	16,762,222
Single-unit truck:						
Panels and pickups	1,239,747	176,595	236,846	246,216	422,536	1,082,193
Other	1,072,841	125,410	144,528	149,807	309,226	728,971
Total	2,312,588	302,005	381,374	396,023	731,762	1,811,164
Truck combinations	521,188	63,672	60,389	42,480	144,929	311,470
All trucks	2,833,776	365,677	441,763	438,503	876,691	2,122,634

[1] Data represent travel of Illinois-registered vehicles in use (2).

TABLE 12

NUMBER OF VEHICLES INVOLVED IN AND DIRECT COST OF TRAFFIC ACCIDENTS PER 10 MILLION VEHICLE-MILES OF TRAVEL

Vehicle Type	Rural Areas	Municipalities				
		Under 5,000	5,000-24,999	25,000-125,000	1,000,000 and Over	Total
(a) Number of Vehicles Involved in Accidents per 10 Million Vehicle-Miles						
Passenger Car	191	390	777	745	665	672
Single-unit truck:						
Panels and pickups	76	427	281	463	523	441
Other	123	187	402	667	640	520
Total	98	327	327	540	572	473
Truck combination	73	165	298	758	587	468
All trucks	95	299	325	573	580	477
(b) Direct Cost of Accidents per 10 Million Vehicle-Miles ($)						
Passenger Car	61,067	57,072	98,729	111,421	144,704	117,996
Single-unit truck:						
Panels and pickups	32,636	31,269	21,415	41,659	35,369	33,077
Other	27,881	23,241	21,116	55,569	42,363	37,575
Total	30,430	27,936	21,302	46,921	38,325	34,887
Truck combination	39,511	82,000	85,494	81,811	83,571	83,383
All trucks	32,136	37,349	30,146	51,225	45,979	42,281

Direct costs of accident involvements per 10 million vehicle-miles of travel are shown in the right half of Table 12. On the basis of relative exposure, the cost of passenger car involvements ranged from $61,100 per 10 million vehicle-miles in rural areas to $118,000 in municipalities. Similar comparisons for single-unit trucks indicated a range of $30,400 to $34,900; truck combinations, $39,500 to $83,400.

The comparison of involvement and cost rates in rural areas vs municipalities points to the fact that many of the accidents in cities were relatively minor events. For all classes of vehicles considered in the study, involvement rates ranged from 170 per 10 million vehicle-miles of travel in rural areas to 650 in municipalities, or a ratio of 1 to 3.8. Cost rates, on the other hand, ranged from $54,700 per 10 million vehicle-miles in rural areas to $109,500 in municipalities, or a ratio of 1 to 2.

An analysis of the types of accidents shows that nearly one-half of all accidents in municipalities were collisions with parked vehicles and rear-end collisions. These two types of accidents accounted for only 15 percent of the total direct costs of accidents in municipalities. But regardless of the severity or costs of specific types of accidents, the fact still remains that a large part of the accident problem is concentrated in cities, and prevailing vehicle insurance rates for urban residents reflect that condition. Eighty-five percent of the accident involvements occurring in the State during the study year took place in municipalities, and those events accounted for 75 percent of the total direct costs of accidents.

A rather unusual finding of the study was the doubling of the accident cost rate for truck combinations in cities vs rural areas. A similar relationship did not hold for single-unit trucks. As shown in Table 7, the cost of approximately 0.8 cent per vehicle-mile for combinations was quite uniform for all city size groups. A further analysis of these data indicated that the rates for combinations were influenced to a considerable extent by the occurrence of a limited number of fatal and nonfatal injury accidents in which the costs exceeded $10,000 per involvement.

TABLE 13

NUMBER OF MUNICIPALITIES AND POPULATION FOR VARIOUS POPULATION GROUPS

Population Group	Number of Cities	1958 Population
Urban:		
Under 5,000	1,026	1,135,700
5,000 - 24,999	138	1,399,500
25,000 - 125,000	33	1,750,100
1,000,000 and over	1	3,614,100
Subtotal	1,198	7,899,400
Rural	--	1,762,700
Total	1,198	9,662,100

As a matter of interest, Table 13 shows the number of municipalities and population for each city size group given in Tables 10, 11, and 12 and total population.

The population group of 1,000,000 and over obviously applies to Chicago. Incorporated places surrounding the corporate area of Chicago (such as Evanston, Oak Park, Berwyn, and Cicero) were included in the lesser population groups. Forty-six percent of the accident involvements and 56 percent of the total costs of accidents occurring in municipalities of the State were traceable to the corporate area of Chicago. This finding was not unusual, as 46 percent of the urban population of the State resided in the one city, and 45 percent of the statewide municipal travel was performed there. In relating the costs of passenger car and truck accidents to travel of these vehicles in Chicago, the rate per vehicle-mile was found to be $0.035.

A recent publication of the Chicago Area Transportation Study (CATS) provides useful comparisons of accident costs and rates for streets and highways of the Greater Chicago area (3). (Data for the study were based on the statewide accident cost study.) The area covered in the analysis included Cook and Du Page Counties, the confines of which were nearly equivalent to the perimeters of the CATS study.

The locations of traffic accidents occurring in Cook and Du Page Counties during 1958 were classified on the basis of three systems: expressways, arterials, and local streets. Accident rates and costs developed in the analysis are given in Table 14.

The cost of accidents per vehicle-mile of travel on all street systems of the two counties was calculated as $0.0132, which was slightly less than the rate of $0.0135 for the corporate area of Chicago. Of primary interest is the range in costs per vehicle-mile by street systems: expressways, $0.0031; arterials, $0.0107 and local streets, $0.0309. Frequency rates were based on the number of accidents per 10 million vehicle-miles rather than involvements, and thus direct comparisons cannot be made with the data in Table 12. (In the CATS analysis, a conversion factor of 1.89 involvements per traffic accident was used.) Results show that the chance of being involved in a traffic accident on a local street was 20 times greater than on an expressway; on arterial streets, the accident rate was nearly 5 times that of expressways.

Related to Highway Systems

Tables 15 and 16 provide the necessary information to appraise the major highway systems of the State on the basis of accident frequencies and costs. The same limitations apply to this series of tables as those mentioned in connection with Tables 4, 5, and 6. Sampling variability should be kept in mind when viewing the detailed information. Values shown for subtotals and totals obviously are supported by a greater number of sample cases than the component values that make up the totals. Table cells believed to have too few sample cases to provide significant comparisons are indicated by the footnote to Table 17. No estimates of sampling error have been computed, however.

TABLE 14

ACCIDENT RATES AND COSTS, COOK AND DU PAGE COUNTIES, 1958

Street System	Rate per 10 Million Vehicle-Miles	
	Number of Accidents	Direct Cost ($)
Expressways	51	30,800
Arterials	243	107,200
Local streets	1,021	309,400
All systems	347	132,400

TABLE 15

NUMBER OF VEHICLES INVOLVED IN AND DIRECT COSTS OF TRAFFIC ACCIDENTS
BY MAJOR VEHICLE TYPE AND HIGHWAY SYSTEM

Highway System	Illinois-Registered Passenger Cars			Single-Unit Trucks[1]			Truck Combinations			Trucks, All Types		
	Rural	Municipal	Total	Rural	Municipal	Total	Rural	Municipal	Total	Rural	Municipal	Total
(a) Number of Vehicles Involved in Accidents												
Federal-aid primary and State highways	88,809	221,656	310,465	10,855	17,485	28,340	3,082	5,257	8,339	13,937	22,742	36,679
Federal-aid secondary:												
State highways	19,876	5,928	25,804	788	667	1,455	36	33	69	824	700	1,524
Local roads	14,166	4,135	18,301	1,714	24	1,738	38	--	38	1,752	24	1,776
Subtotal	34,042	10,063	44,105	2,502	691	3,193	74	33	107	2,576	724	3,300
Non-Federal-aid:												
State highways	9,330	111,402	120,732	1,534	12,165	13,699	252	2,025	2,277	1,786	14,190	15,976
Local roads	58,794	783,562	842,356	8,144	56,356	64,500	373	7,257	7,630	8,517	63,613	72,130
Subtotal	68,124	894,964	963,088	9,678	68,521	78,199	625	9,282	9,907	10,303	77,803	88,106
All roads and streets:												
State highways	118,015	338,986	457,001	13,177	30,317	43,494	3,370	7,315	10,685	16,547	37,632	54,179
Local roads	72,960	787,697	860,657	9,858	56,380	66,238	411	7,257	7,668	10,269	63,637	73,906
Total	190,975	1,126,683	1,317,658	23,035	86,697	109,732	3,781	14,572	18,353	26,816	101,269	128,085
(b) Direct Cost of Accidents with Illinois-Registered Vehicles ($)												
Federal-aid primary and State highways	34,089,866	45,582,939	79,672,805	4,543,900	1,305,646	5,849,546	1,510,563	1,743,175	3,253,738	6,054,463	3,048,821	9,103,284
Federal-aid secondary:												
State highways	3,292,274	1,270,202	4,562,476	144,672	95,649	240,321	4,641	788	5,429	149,313	96,437	245,750
Local roads	4,611,364	327,622	4,938,986	429,755	231	429,986	315,935	--	315,935	745,690	231	745,921
Subtotal	7,903,638	1,597,824	9,501,462	574,427	95,880	670,307	320,576	788	321,364	895,003	96,668	991,671
Non-Federal-aid:												
State highways	2,963,087	28,358,274	31,321,361	337,210	1,146,764	1,483,974	98,502	298,835	397,337	435,712	1,445,599	1,881,311
Local roads	16,025,291	122,248,701	138,273,992	1,591,683	3,829,322	5,421,005	129,648	554,325	683,973	1,721,331	4,383,647	6,104,978
Subtotal	18,988,378	150,606,975	169,595,353	1,928,893	4,976,086	6,904,979	228,150	853,160	1,081,310	2,157,043	5,829,246	7,986,289
All roads and streets:												
State highways	40,345,227	75,211,415	115,556,642	5,025,782	2,548,059	7,573,841	1,613,706	2,042,798	3,656,504	6,639,488	4,590,857	11,230,345
Local roads	20,636,655	122,576,323	143,212,978	2,021,438	3,829,553	5,850,991	445,583	554,325	999,908	2,467,021	4,383,878	6,850,899
Total	60,981,882	197,787,738	258,769,620	7,047,220	6,377,612	13,424,832	2,059,289	2,597,123	4,656,412	9,106,509	8,974,735	18,081,244

[1]Includes 1,550 trucks of unknown type involved in traffic accidents; 487 of which were involved in rural accidents and 1,063 in municipal accidents.

Accident involvement and cost rates (Table 17) point to the fact that passenger car drivers traveling on local rural roads and on city streets (principally of the residential class) experienced more accidents on a vehicle-mile basis than when driving on State highways. Rates on rural State highways were 173 involvements per 10 million vehicle-miles as compared to 232 involvements on local roads, or a ratio of 1 accident involvement on State highways for every 1.3 involvements on local roads. In municipalities, the rates per 10 million vehicle-miles were 519 and 770, respectively, or a ratio of 1 to 1.5. Costs per vehicle-mile for passenger car involvements ranged from $0.0059 on rural State highways to $0.0066 on local rural roads. A similar comparison for municipalities indicated costs of $0.0115 and $0.0120. Involvement ratios were somewhat greater in the State-local comparisons than were the cost ratios, which indicates that accidents on the local systems tended to be less severe or costly.

Involvement rates for trucks of all types were higher on local roads and streets than on State highways, but costs per vehicle-mile indicated an inverse relation.

A comparison of involvement and cost rates on the basis of the three classes of highways (Federal-aid primary, Federal-aid secondary, and non-Federal-aid) is not too conclusive. However, the emphasis placed on improving the design of major highways shows some benefits from the standpoint of accident frequencies and costs. One principal observation is that the roads and streets not a part of the Federal-aid systems should not be overlooked in accident reduction programs. This class of roads and streets, composed largely of county and township roads in rural areas and residential streets in municipalities, is representative of 82 percent of the road and street mileage of the State. During the year of the study, these facilities accounted for 51 percent of the travel, 73 percent of the accident involvements, and 64 percent of the total direct costs of accidents.

The percentage distribution of travel, accident involvements, and accident costs is shown in Figure 12 for the three classes of highways. The system classifications used in the study are fairly realistic from the standpoint of vehicle usage, particularly in rural areas. A

TABLE 16

IN-STATE TRAVEL OF ILLINOIS-REGISTERED PASSENGER CARS AND TRUCKS, DISTRIBUTED BY HIGHWAY SYSTEMS[1]

Highway System	In-State Travel (thousands of vehicle-miles)											
	Passenger Cars			Single-Unit Trucks			Truck Combinations			Trucks, All Types		
	Rural	Municipal	Total	Rural	Municipal	Total	Rural	Municipal	Total	Rural	Municipal	Total
Federal-aid primary and State highways	5,844,957	4,985,517	10,830,474	1,292,470	560,818	1,853,288	473,874	162,882	636,756	1,766,344	723,700	2,490,044
Federal-aid secondary highways:												
State highways	409,629	137,276	546,905	78,716	18,874	97,590	6,051	2,422	8,473	84,767	21,296	106,063
Local roads	1,066,522	133,976	1,200,498	223,545	14,263	237,808	5,413	647	6,060	228,958	14,910	243,868
Subtotal	1,476,151	271,252	1,747,403	302,261	33,137	335,398	11,464	3,069	14,533	313,725	36,206	349,931
Non-Federal-aid highways:												
State highways	586,552	1,403,184	1,989,736	126,168	155,565	281,733	24,595	33,061	57,656	150,763	188,626	339,389
Local roads	2,078,424	10,102,269	12,180,693	591,689	1,061,644	1,653,333	11,255	112,458	123,713	602,944	1,174,102	1,777,046
Subtotal	2,664,976	11,505,453	14,170,429	717,857	1,217,209	1,935,066	35,850	145,519	181,369	753,707	1,362,728	2,116,435
All roads and streets:												
State highways	6,841,138	6,525,977	13,367,115	1,497,354	735,257	2,232,611	504,520	198,365	702,885	2,001,874	933,622	2,935,496
Local roads	3,144,946	10,236,245	13,381,191	815,234	1,075,907	1,891,141	16,668	113,105	129,773	831,902	1,189,012	2,020,914
Total	9,986,084	16,762,222	26,748,306	2,312,588	1,811,164	4,123,752	521,188	311,470	832,658	2,833,776	2,122,634	4,956,410

[1]Data source (2).

TABLE 17

NUMBER OF VEHICLES INVOLVED IN AND DIRECT COSTS OF TRAFFIC ACCIDENTS PER 10 MILLION VEHICLE-MILES OF TRAVEL, BY MAJOR VEHICLE TYPE AND HIGHWAY SYSTEM

Highway System	Passenger Cars			Single-Unit Trucks			Truck Combinations			Trucks, All Types		
	Rural	Municipal	Total	Rural	Municipal	Total	Rural	Municipal	Total	Rural	Municipal	Total
(a) Number of Illinois-Registered Vehicles Involved in Accidents per 10 Million Vehicle-Miles												
Federal-aid primary and State highways	152	445	287	84	312	153	65	323	131	79	314	147
Federal-aid secondary:												
State highways	485	432	472	100	--[1]	149	--[1]	--[1]	--[1]	97	--[1]	144
Local roads	133	--[1]	152	77	--[1]	73	--[1]	--	--[1]	77	--[1]	73
Subtotal	231	371	252	83	--[1]	95	--[1]	--[1]	--[1]	82	--[1]	94
Non-Federal-aid:												
State highways	159	794	607	122	782	486	--[1]	613	395	118	752	471
Local roads	283	776	692	138	531	390	--[1]	645	617	141	542	406
Subtotal	256	778	680	135	563	404	--[1]	638	546	137	571	416
All roads and streets:												
State highways	173	519	342	88	412	195	67	369	152	83	403	185
Local roads	232	770	643	121	524	350	--[1]	642	591	123	535	366
Total	191	672	493	100	479	266	73	468	220	95	477	258
(b) Direct Cost of Accidents per 10 Million Vehicle-Miles ($)												
Federal-aid primary and State highways	58,324	91,431	73,564	35,157	23,281	31,563	31,877	107,021	51,099	34,277	42,128	36,559
Federal-aid secondary:												
State highways	80,372	92,529	83,424	18,379	--[1]	24,626	--[1]	--[1]	--[1]	17,615	--[1]	23,170
Local roads	43,237	--[1]	41,141	19,225	--[1]	18,081	--[1]	--	--[1]	32,569	--[1]	30,587
Subtotal	53,542	58,906	54,375	19,004	--[1]	19,985	--[1]	--[1]	--[1]	28,528	--[1]	28,339
Non-Federal-aid:												
State highways	50,517	202,099	157,415	26,727	73,716	52,673	--[1]	90,389	68,915	28,900	76,638	55,432
Local roads	77,103	121,011	113,519	26,901	36,070	32,788	--[1]	49,292	55,287	28,549	37,336	34,355
Subtotal	71,252	130,901	119,683	26,870	40,881	35,683	--[1]	58,629	59,619	28,619	42,776	37,735
All roads and streets:												
State highways	58,974	115,249	86,448	33,564	34,655	33,924	31,985	102,982	52,021	33,166	49,173	38,257
Local roads	65,618	119,747	107,026	24,796	35,594	30,939	--[1]	49,010	77,051	29,655	36,870	33,900
Total	61,067	117,996	96,742	30,473	35,213	32,555	39,511	83,383	55,922	32,136	42,281	36,481

[1] Sample too small to provide significant data (20 or less sample cases).

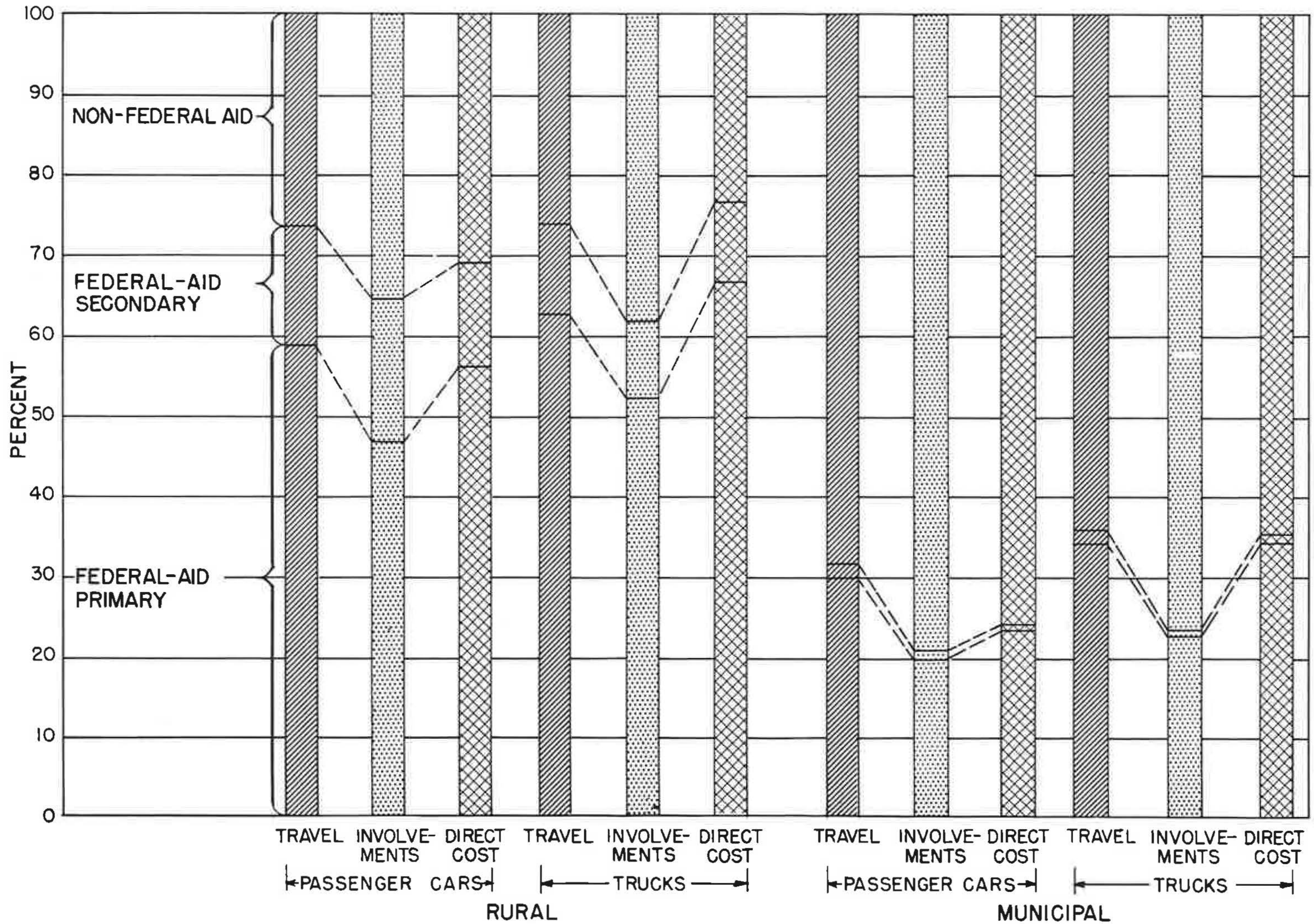

Figure 12. Percentage distribution of travel, accident involvements, and accident costs on basis of major vehicle type, rural and municipal location, and highway system.

TABLE 18

IN-STATE TRAVEL OF ILLINOIS-REGISTERED PASSENGER CARS AND TRUCKS, DISTRIBUTED BY HIGHWAY SYSTEMS AND AVERAGE DAILY TRAVEL PER MILE OF ROAD OR STREET

Item of Comparison	Federal-Aid Primary and State Highways	Federal-Aid Secondary Highways			Non-Federal-Aid Highways			All Roads and Streets		
		State Highways	Local Roads	Total	State Highways	Local Roads	Total	State Highways	Local Roads	Total
(a) Travel in Rural Areas										
Miles of rural roads	8,625	1,618	10,050	11,668	2,391	79,503	81,894	12,634	89,553	102,187
Passenger car travel:										
Annual (1,000 v-m)	5,844,957	409,629	1,066,522	1,476,151	586,552	2,078,424	2,664,976	6,841,138	3,144,946	9,986,084
Average daily (1,000 v-m)	16,014	1,122	2,922	4,044	1,607	5,694	7,301	18,743	8,616	27,359
Average daily per mile of road	1,857	693	291	347	672	72	89	1,484	96	268
Truck travel:										
Annual (1,000 v-m)	1,766,344	84,767	228,958	313,725	150,763	602,944	753,707	2,001,874	831,902	2,833,776
Average daily (1,000 v-m)	4,839	233	627	860	413	1,652	2,065	5,485	2,279	7,764
Average daily per mile of road	561	144	62	74	173	21	25	434	25	76
(b) Travel in Municipalities										
Miles of streets	1,498	203	209	412	988	18,192	19,180	2,689	18,401	21,090
Passenger-car-travel:										
Annual (1,000 v-m)	4,985,517	137,276	133,976	271,252	1,403,184	10,102,269	11,505,453	6,525,977	10,236,245	16,762,222
Average daily (1,000 v-m)	13,659	376	367	743	3,844	27,678	31,522	17,879	28,045	45,924
Average daily per mile of street	9,118	1,852	1,756	1,803	3,891	1,521	1,643	6,649	1,524	2,178
Truck travel:										
Annual (1,000 v-m)	723,700	21,296	14,910	36,206	188,626	1,174,102	1,362,728	933,622	1,189,012	2,122,634
Average daily (1,000 v-m)	1,983	58	41	99	516	3,217	3,733	2,557	3,258	5,815
Average daily per mile of street	1,324	287	195	241	523	177	195	951	177	276
(c) Total Travel										
Miles of roads and streets	10,123	1,821	10,259	12,080	3,379	97,695	101,074	15,323	107,954	123,277
Passenger car travel:										
Annual (1,000 v-m)	10,830,474	546,905	1,200,498	1,747,403	1,989,736	12,180,693	14,170,429	13,367,115	13,381,191	26,748,306
Average daily (1,000 v-m)	29,673	1,498	3,289	4,787	5,451	33,372	38,823	36,622	36,661	73,283
Average daily per mile of road and street	2,931	823	321	396	1,613	342	384	2,390	340	594
Truck travel:										
Annual (1,000 v-m)	2,490,044	106,063	243,868	349,931	339,389	1,777,046	2,116,435	2,935,496	2,020,914	4,956,410
Average daily (1,000 v-m)	6,822	291	668	959	929	4,869	5,798	8,042	5,537	13,579
Average daily per mile of road and street	674	160	65	79	275	50	57	525	51	110

preferred classification for major cities would be expressways, arterials, and residential streets. Streets of the Federal-aid secondary classification represent a very small portion of the total municipal mileage, as shown in Table 18.

Table 19 shows average daily travel of Illinois passenger cars and trucks on the three systems during 1958.

TABLE 19

AVERAGE DAILY TRAVEL, ILLINOIS PASSENGER CARS AND TRUCKS, 1958

System	Vehicles per Day per Mile of Road or Street	
	Rural	Municipal
Federal-aid primary	2,418	10,442
Federal-aid secondary	421	2,044
Non-Federal-aid	114	1,838
All	344	2,454

SUMMARY OF FINDINGS

The major findings of the Illinois accident cost study, as discussed herein, were as follows:

1. Direct costs of motor vehicle accidents and incidents involving Illinois-registered passenger cars during 1958 totaled $309.5 million. For Illinois trucks, such costs amounted to $29.3 million. These events, occurring both on and off the highways and in and out of Illinois, resulted in costs to persons and property totaling $1/3 billion, or an amount equivalent to three-fifths of the total outlay of funds by State, Federal, and local governments for the construction and maintenance of Illinois roads and streets during 1958.

The $1/3 billion figure represented an average cost of $928,000 per day—$104 per vehicle in use, $84 for each person with a permit to drive, and $35 per capita.

2. Approximately 1.3 million Illinois passenger cars were involved in traffic accidents on Illinois highways which resulted in costs of $258.8 million, or an average of $196 per event; similarly, 128,000 trucks were involved in traffic accidents costing $18.1 million, or an average of $141 per event. A further comparison on the basis of exposure indicated costs of $0.0097 per passenger-car mile and $0.0036 per truck-mile.

Three-fourths of the 1.3 million passenger car involvements and four-fifths of the 128,000 truck involvements were not recorded in the official accident files of the State. Although most of these events were minor happenings in which property damage costs were below the legal reporting minimum, they accounted for 42 percent of the total direct costs of passenger car accidents and 55 percent in the case of truck accidents.

3. The distribution of the accident cost dollar for all severity classes of accidents was as follows: property damage, $0.60; treatment of injuries, $0.08; loss of use of vehicle, $0.01; value of work time lost, $0.08; legal and court fees, $0.10; and damage awards and settlements in excess of known costs, $0.13.

4. The problems inherent in sampling the "universe" of traffic accidents for the purpose of determining costs were made evident by the wide range in costs found for the different severity classes of accidents. Extreme cost values for individual sample cases were as follows: fatal injury involvements, $136,000; nonfatal injury, $73,000; and property damage only, $30,000. In contrast, median cost values were $2,280 for fatal injury involvements, $310 for nonfatal injury, and $50 for property damage only involvements.

5. Passenger car owners were involved in accidents within municipalities $3\frac{1}{2}$ times as often as in rural areas. For truck owners, the ratio was 1 involvement in rural areas for every 5 involvements in municipalities. Costs per passenger-car mile ranged from $0.0061 in rural areas to $0.0118 in municipalities; similarly, costs per truck-mile ranged from $0.0032 to $0.0042, respectively.

6. Comparisons made of accident frequencies and costs by major highway systems indicated that roads and streets of a local character had the least desirable rates. Many of the accidents that took place on residential streets were relatively minor events, but when considered in the aggregate they represented a sizeable portion of the total direct costs of traffic accidents.

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Benefit-Cost Ratios: A Word of Caution

GERALD W. SMITH, Associate Professor of Industrial Engineering, Iowa State University

•IN THE EVALUATION of capital expenditure proposals for public projects, especially in highway facility planning, a method of comparing design alternatives called the benefit-cost ratio is widely used. The author offers a word of caution in the application of this method and makes a suggestion for those who compare the economy of design alternatives. The study of capital expenditure evaluation is generally referred to as engineering economy (1 through 10).

The benefit-cost ratio is a method of comparing economic alternatives. It is used to determine (a) which alternative, if any, is worthwhile, and (b) which alternative offers the greatest economy. Specifically, it is the ratio of annual benefits (such as reduced cost to users of the facility) to annual costs (such as maintenance, operation, and the average annual share of capital costs). This method is used in comparing alternatives for many types of public projects (e.g., water treatment services, recreational facilities, flood control, and public parks); the examples which follow, however, will be in the language of highway alternatives. The following notations are used:

S = investment costs on an annual basis;
M = maintenance costs on an annual basis;
$S + M$ = highway costs on an annual basis;
R = road user costs on an annual basis;
I = investment;
n = estimated life of facility, in years; and
i = interest rate.

The subscripts 0 and 1 identify data pertaining to the original and proposed road facilities, respectively.

CRITERIA FOR ECONOMY

Because the benefit-cost ratio is the ratio of annual benefits to annual costs (1, p. 27), the ratio for the notation given can be shown as

$$\text{Benefit-cost} = \frac{R_0 - R_1}{S_1 + M_1 - S_0 - M_0} \quad (1)$$

If the resulting ratio is higher than the prescribed minimum ratio the proposal "passes" the benefit-cost ratio test.

Rate of return can be computed by simply equating annual savings with annual costs of obtaining such savings:

$$R_0 - R_1 + M_0 - M_1 = (I_1 - I_0)\ (\text{capital recovery factor in which } n \text{ is given, and } i \text{ is unknown}) \quad (2)$$

Eq. 2 is then solved for i. If the result is higher than the prescribed minimum rate of return, the proposal "passes" the rate of return test.

Example 1

Five alternative proposals for a highway facility are being considered. Each requires an investment of $20,000 and each has a life of 10 years. A 5 percent interest rate is

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used in computing capital recovery. Other estimates pertaining to the alternatives are given in Table 1. For each alternative in Table 1, find (a) the benefit-cost ratio, and (b) the rate of return on the investment.

Solution of Example 1

$$\text{Benefit-cost ratio} = \frac{R_0 - R_1}{S_1 + M_1 - S_0 - M_0} = \frac{R_0 - R_1}{(S_1 - S_0) - (M_0 - M_1)} \quad (3)$$

Because

$$S_1 - S_0 = (I_1 - I_0)\ (\text{capital recovery factor in which } i = 5\%,\ n = 10)$$
$$= (20,000)\ (0.1295)$$
$$= \$2,590$$

Then for alternative A,

$$\text{Benefit-cost ratio} = \frac{6,000}{2,590 + 410} = 2.0$$

and similarly for alternatives B, C, D, and E. Rate of return can be computed by

$$R_0 - R_1 + M_0 - M_1 = (I_1 - I_0)\ (\text{capital recovery factor in which } i = ?,\ n = 10)$$

for alternative A (using CRF for capital recovery factor):

$$6,000 - 410 = \$20,000\ (CRF - i - 10)$$
$$(CRF - i - 10) = 0.2795$$

by use of tables (4, pp. 538-557) and interpolation:

$$i \simeq 25 \text{ percent}$$

and similarly for alternatives B, C, D, and E. Results of the calculations are given in Table 2.

Example 2

Six alternative proposals for a highway facility are being considered. An interest rate of 5 percent is to be used. Estimates pertaining to competing alternatives are given in Table 3.

For each alternative in the table, find (a) the benefit-cost ratio, (b) the rate of return on the investment, and (c) the savings-cost ratio, $(R_0 - R_1 + M_0 - M_1) / (S_1 - S_0)$.

Solution of Example 2

Results in Table 4 are obtained by calculations similar to those of example 1.

TABLE 1

ESTIMATES PERTAINING TO CERTAIN HIGHWAY ALTERNATIVES

Alternative	Decrease in Road-User Costs, R_0-R_1 (\$)	Decrease in Maintenance Costs, M_0-M_1 (\$)	Gross Savings R_0-R_1 + M_0-M_1 (\$)
A	6,000	-410	5,590
B	3,000	1,090	4,090
C	1,000	2,090	3,090
D	200	2,490	2,690
E	-1,000	3,090	2,090

TABLE 2

COMPARATIVE ECONOMY OF CERTAIN HIGHWAY ALTERNATIVES BY TWO METHODS

Alternative	Decrease in Road-User Costs, R_0-R_1 ($)	Decrease in Maintenance Costs, M_0 - M_1 ($)	Gross Savings R_0-R_1 + M_0-M_1 ($)	Benefit-Cost Ratio[1]	Rate of Return (%)[2]
A	6,000	-410	5,590	2.0	25
B	3,000	1,090	4,090	2.0	16
C	1,000	2,090	3,090	2.0	9
D	200	2,490	2,690	2.0	6
E	-1,000	3,090	2,090	2.0[3]	1

[1]Rounded to nearest tenth.
[2]Rounded to nearest whole percent.
[3]This is a rather facetious alternative and ratio; although negative numerator and denominator cancel each other, ratio only indicates that every dollar decrease in cost to agency that provides highway facility is accompanied by two-dollar increase in cost to road user.

TABLE 3

ESTIMATES PERTAINING TO CERTAIN HIGHWAY ALTERNATIVES

Alternative	Decrease in Road-User Costs, R_0 - R_1 ($)	Decrease in Maintenance Costs M_0 - M_1 ($)	Gross Savings R_0-R_1 + M_0-M_1 ($)	Investment I_1 - I_0 ($)	Estimated Life (yr)
F	300	1,000	1,300	8,000	10
G	628	1,000	1,628	10,000	10
H	15,275	1,000	16,275	100,000	10
I	5,501	-4,000	1,501	10,000	50
J	4,188	-2,195	1,993	10,000	10
K	4,038	-1,055	2,983	10,000	5

Analysis

The preceding calculations show that for any given benefit-cost ratio the rate of return on investment is not fixed. In example 1, five alternatives having benefit-cost ratio of 2.0 exhibit returns that vary from 1 to 25 percent. The decision indicated by the benefit-cost ratio method does not agree with the decision indicated by rate of return method.

If public funds should be allocated to their various purposes so as to maximize the long-run gains (such as reduced cost to users of the facility and decreased maintenance cost to operators of the facility) of such investments, it follows that a criterion that satisfactorily measures the desirability of alternatives is mandatory.

In example 1, the benefit-cost ratio fails to reveal the investment alternative that maximizes the return on public funds invested. In example 2, the benefit-cost ratio makes three equivalent alternatives (F, G, and H) appear to be not equivalent. Worse yet, the alternatives that would maximize the return on public funds (alternatives I, J, or K) appear by the benefit-cost ratio method to be least desirable of the six alternatives. The examples show three crucial defects in the benefit-cost ratio method:

1. It sometimes fails to discriminate so as to point out the alternative that maximizes the return on public funds.
2. It sometimes discriminates among alternatives that provide equivalent returns on public funds.
3. It sometimes yields results that point to the selection of alternatives that do not maximize the return on public funds.

These defects in the benefit-cost ratio method are not corrected by the savings-cost ratio method. As can be seen in the comparison of alternatives I, J, and K, the savings-cost ratio method is responsive to differences in the lives of alternatives; it will as a matter of fact, generally bias the results to favor the longer-lived alternative. Interestingly enough, the savings-cost ratio method is similar to an inverted payoff period; still more interesting is that the bias introduced is just the opposite. Payoff period as a criterion tends to favor short-lived alternatives; savings-cost ratio as a criterion tends to favor long-lived alternatives.

If the benefit-cost ratio method fails to discriminate properly in the instances shown, then it can hardly be expected to determine satisfactorily the sequence of investment proposals that should be followed by a public body.

The preceding examples suggest that the rate-of-return method should be used at least as a check in the evaluation of proposed capital expenditures for public facilities. When there is more than a single capital expenditure and several life expectancies are involved, or when a deferred expenditure is involved, the rate of return is computed by successive trial values. Although the rate-of-return method can be more complex computationally, proper evaluation of the usually large capital expenditures for proposed public facilities compensates many times over for the extra effort. Example 3 demonstrates that even the more complex problems require only added computational time.

Example 3

It has been proposed that a certain highway be replaced by a relocated route. Estimates of lives and costs of the relocated route are 20 years and $100,000 for the paving, 40 years and $200,000 for the grading and drainage, 60 years and $50,000 for the right-of-way.

It is expected that the proposed route will require $40,000 every ten years for major roadway rehabilitation. Road user costs are expected to decrease $92,000 per year with the proposed route, whereas maintenance costs are expected to increase by $20,000 per year. Find the rate of return on the investment.

Solution of Example 3

Equivalent annual costs of capital expenditures are obtained by multiplying each expenditure by the appropriate capital recovery factor (CRF). For recurring deferred

TABLE 4

COMPARATIVE ECONOMY OF CERTAIN HIGHWAY ALTERNATIVES BY THREE METHODS

Alternative	Decrease in Road-User Costs, $R_0 - R_1$ ($)	Decrease in Maintenance Costs, $M_0 - M_1$ ($)	Gross Savings, $R_0-R_1 + M_0-M_1$ ($)	Investment, $I_1 - I_0$ ($)	Estimated Life (yr)	Benefit-Cost Ratio[1]	Rate of Return (%)	Savings Cost Ratio[1]
F	300	1,000	1,300	8,000	10	8.3	10	1.4
G	628	1,000	1,628	10,000	10	2.1	10	1.3
H	15,275	1,000	16,275	100,000	10	1.3	10	1.3
I	5,501	-4,000	1,501	10,000	50	1.2	15	2.7
J	4,188	-2,195	1,993	10,000	10	1.2	15	1.5
K	4,038	-1,055	2,983	10,000	5	1.2	15	1.3

[1]Rounded to nearest tenth..
[2]Rounded to nearest whole percent.

expenditures, the equivalent annual cost is obtained by multiplying the deferred expenditure by the sinking fund factor (SFF). For nonrecurring deferred expenditures, the equivalent annual cost is obtained by multiplying the deferred expenditure by the present worth factor for a single sum and then by the capital recovery factor. In example 3, a solution is obtained as follows:

$$\text{Benefits} = \text{Cost of obtaining benefits} \tag{4}$$

$$\$92,000 - \$20,000 = \$100,000\ (CRF - i - 20) + \$200,000\ (CRF - i - 40) + \$\ 50,000\ (CRF - i - 60) + \$\ 40,000\ (SFF - i - 10)$$

and the solution is obtained by successive trials:

At i = 15 percent,

$$\$72,000 \neq \$15,976 + \$30,112 + \$7,500 + \$1,970$$
$$\neq \$55,568$$

At i = 20 percent,

$$\$72,000 = \$20,536 + \$40,028 + \$10,000 + \$1,541$$
$$= \$72,105$$

Therefore, the rate of return is about 20 percent.

SUMMARY

The suggested use of the rate of return method for public projects (as a check or as an independent method) is not as drastic as it appears. The comprehensive data prepared by AASHO (1) on road user costs would be used exactly as before; the changes in maintenance costs and proposed expenditures and lives would be estimated as at present. The benefit-to-cost concept need not be lost; finding of the rate of return requires computation of the ratio of gross annual savings to users and operators of the facility (benefits) to investment (cost). The author is not alone, nor even first (7, p. 8) to suggest that AASHO consider changing to the rate-of-return method of evaluating economic alternatives. The danger involved in continued use of only the benefit-cost ratio method is in the possibility that some high-yield projects will be delayed or denied because funds have been exhausted in some low-yield projects.

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Discussion

GERALD A. FLEISCHER, Assistant Professor of Industrial Engineering, University of Michigan*—Professor Smith offers two examples of application of the benefit-cost ratio method which, he claims, show the three crucial defects of (a) sometimes failing to discriminate so as to point out the alternative which maximizes the return on public funds; (b) sometimes discriminating among alternatives which provide equivalent returns on public funds; and (c) sometimes yielding results which point to the selection of alternatives which do not maximize the return on public funds.

In view of these criticisms, Professor Smith suggests that "the rate of return method should be used at least as a check in the evaluation of proposed expenditures for public facilities," and offers a third example demonstrating the use of this preferred method.

The writer objects to the conclusion that the benefit-cost method is conceptually invalid. Although it is agreed that the rate of return method is preferable, this is due to a number of reasons other than inherent verity.

The purpose, then, of this discussion is to demonstrate that the benefit-cost ratio method, when properly applied, is a valid technique for choosing among alternatives competing for limited resources. This is done by using the same examples offered by the author in his attempt to demonstrate the opposite. That is, it will be shown that the rate of return and benefit-cost ratio methods are equivalent.

Notation

To maintain consistency with the basic paper, the author's notation has been retained with only minor changes.

To convert an initial investment I to an equivalent uniform series S, it is necessary to use the appropriate capital recovery factor for a given interest rate i and a given number of interest periods n. This factor is indicated by (crf - i% - n).

Basic Equations

The benefit-cost ratio is commonly defined as the ratio of annual benefits to annual costs, although there exists some question as to which consequences of an investment are benefits and which are costs. Clearly, a benefit is a negative cost, and vice versa. Table 5 gives the various combinations of notation elements.

TABLE 5

COMBINATIONS IN BENEFIT-COST ANALYSES

Costs	Symbol			
	Old	New	Benefits	Costs
Road user	R_0	R_1	$R_0 - R_1$	$R_1 - R_0$
Maintenance	M_0	M_1	$M_0 - M_1$	$M_1 - M_0$
Investment	S_0	S_1	$S_0 - S_1$	$S_1 - S_0$

It is generally agreed that effects on road user costs should be included in the numerator of the benefit-cost ratio, and it is likewise agreed that changes in investment costs should be shown in the denominator. However, there are several ways of handling the increase (or decrease) in maintenance costs, as follows:

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$$B/C = \frac{(R_0 - R_1)}{(S_1 - S_0) + (M_1 - M_0)} \quad (1)$$

$$B/C = \frac{(R_0 - R_1)}{(S_1 - S_0) - (M_0 - M_1)} \quad (3)$$

$$B/C = \frac{(R_0 - R_1) + (M_0 - M_1)}{(S_1 - S_0)} \quad (5)$$

The minor differences between Eqs. 1 and 3 are obvious; they are essentially the same. Eq. 5 differs from the other two in defining a reduction in maintenance costs as a benefit rather than a negative cost. (The choice of numerator or denominator for maintenance costs is irrelevant, although this question has been the source of considerable controversy in recent years. The acceptance criterion is whether or not the benefit-cost ratio exceeds unity, thus the absolute value of the ratio is unimportant. When the same number is added or subtracted to both the numerator and denominator of a fraction, the fraction cannot change from greater than one to less than one, or vice versa. One must only insure that the definition of the ratio is applied consistently in any given problem.)

The author defines his benefit-cost ratio as including the maintenance costs in the denominator (as in Eqs. 1 and 3), and uses the term "savings-cost ratio" when shifting the effect of changes in maintenance costs to the numerator (as in Eq. 5).

To find the unknown rate of return in certain special cases (such as Example 1), the following equation may be used with n given:

$$(\text{crf} - i\% - n) = \frac{(R_0 - R_1) + (M_0 - M_1)}{(I_1 - I_0)} \quad (6)$$

Given the capital recovery factor for a certain n, it is only necessary to consult the appropriate tables for various values of i and interpolate if necessary. (Eq. 6 may be derived quite easily by using Equation 1, 3 or 5, and setting the benefit-cost ratio equal to unity.)

Example 1

Benefit-Cost Ratio Method.—The basic data provided by the author are given in Cols. 1 through 4, Table 6. It is assumed that each alternative has a life of 10 years and that an interest rate of 5 percent per annum is used.

Two observations should be made about the benefit-cost ratios shown in Col. 7. The first, pointed out by Professor Smith, is that the benefit-cost ratio shown for alternative E is spurious. Col. 2 indicates that there is an increase in road user costs accompanied by a smaller decrease in costs to the highway agency, as shown in Col. 6. Or, as the author puts it, "...although the negative numerator and denominator cancel each other, the ratio indicates only that every dollar decrease in cost to the agency that provides the highway facility is accompanied by a two-dollar increase in cost to the road user."

The second point is that only an analysis of incremental benefit-cost ratios will yield the proper solution. Thus, the numbers in Col. 7, Table 6, have no other value than to indicate that alternatives A through D are each acceptable. The incremental analysis is still needed to determine which one should be chosen.

Unfortunately, the author ranked his alternatives in descending, rather than ascending, order of costs. Thus, to simplify the arithmetic, the writer has started with alternative E and worked backward to alternative A. (This procedure simply eases computational effort; the final result is the same regardless of sequence.)

First, alternative E is compared with the possibility of doing nothing; i.e., employing the resources elsewhere rather than investing in the project. Inasmuch as E is not economically feasible, the next move is to D. The result is that annual benefits will increase by \$200 while costs will increase by only \$100. Thus the incremental benefit-cost ratio ($\Delta B/C$) is 2.0.

TABLE 6

EXAMPLE 1:
BENEFIT-COST RATIO SOLUTION

Alt. (1)	$(R_0 - R_1)$ (\$) (2)	$(M_0 - M_1)$ (\$) (3)	$(I_1 - I_0)$ (\$) (4)	$(S_1 - S_0)$[a] (\$) (5)	Col. 5 - 3 (\$) (6)[a]	B/C[b] (7)	B - C[c] (\$) (8)	Compare[d] (9)	ΔB (10)	ΔC (11)	ΔB/C (12)
A	6,000	-410	20,000	2,590	3,000	2.0	3,000	|A/B|	3,000	1,500	2.0
B	3,000	1,090	20,000	2,590	1,500	2.0	1,500	|B/C|	2,000	1,000	2.0
C	1,000	2,090	20,000	2,590	500	2.0	500	|C/D|	800	400	2.0
D	200	2,490	20,000	2,590	100	2.0	100	|D/ϕ|	200	100	2.0
E	-1,000	3,090	20,000	2,590	- 500	2.0	- 500	|E/ϕ|	-	-	-

[a]Col. 4 × (crf - 5% - 10) = 0.1295 Col. 4.
[b]By Eq. 3.
[c]$B - C = (R_0 - R_1) + (M_0 - M_1) - (S_1 - S_0)$.
[d]ϕ denotes the alternative "Do nothing, employ resources elsewhere."

The next question is whether or not alternative C is economically superior to D. The difference between these two is that an \$800 increase in benefits will be accompanied by a \$400 increase in costs. Because the incremental benefit-cost ratio exceeds unity (i.e., 2.0), C is accepted and D is disregarded.

Continuing this process results in the selection of alternative A inasmuch as B is superior to C and A is superior to B. This is the correct answer, as is shown in Col. 8, where the "excess of benefits over costs" values have been computed in a straightforward manner. (The reader may wonder why—if a simple evaluative method such as that described up to Col. 8 is available—there is discussion of a method which requires a rather cumbersome iterative technique. Why indeed? But rather than digress at this point to discuss the philosophy of choice of method, this question is left with the reader. The purpose here is only to demonstrate that the benefit-cost ratio method is valid, regardless of its computational intricacies.)

Rate of Return Method.—Table 7 is a summary of calculations necessary to select the most economic alternative by use of the rate of return method. As before, the basic data for each of the five alternatives are given in Cols. 1 through 4.

Col. 5 is simply a calculation of the numerators appropriate to Eq. 6. The denominator values are given in Col. 4, and Col. 6 represents the capital recovery factors for unknown interest rates i and n = 10 years. The actual (solving) interest rates have not been shown in Col. 7 because they are irrelevant; it is only necessary to know whether or not i is greater than the minimum attractive rate of return, 5 percent. That is, will the highway agency be able to invest its dollars in one of these alternatives at a rate of return greater than 5 percent? Inasmuch as the capital recovery factor for i = 5% and n = 10 is 0.1295, it is only necessary that the values in Col. 6 be greater than this number. Only alternative E fails this test and hence should be omitted from further consideration.

As in the case of the benefit-cost ratio method, it is now necessary to look at the prospective rates of return yielded by increments of investment. This analysis represented by Cols. 8 through 12, follows a pattern similar to the incremental analysis

TABLE 7

EXAMPLE 1: RATE OF RETURN SOLUTION

Alt. (1)	$(R_0 - R_1)$ (\$) (2)	$(M_0 - M_1)$ (\$) (3)	$(I_1 - I_0)$ (\$) (4)	Col. 2 + 3 (\$) (5)	(crf - i% - 10)[a] (6)	i% (7)	Compare (8)	Δ Num.[b] (\$) (9)	Δ Denom.[c] (\$) (10)	Δ CRF[d] (11)	Δ i% (12)
A	6,000	- 410	20,000	5,590	0.2795	> 5	|A/B|	1,500	0	∞	> 5
B	3,000	1,090	20,000	4,090	0.2045	> 5	|B/C|	1,000	0	∞	> 5
C	1,000	2,090	20,000	3,090	0.1545	> 5	|C/D|	400	0	∞	> 5
D	200	2,490	20,000	2,690	0.1345	> 5	|D/ϕ|	2,690	20,000	0.1345	> 5
E	-1,000	3,090	20,000	2,090	0.1045	< 5	|E/ϕ|	-	-	-	-

[a]$(\text{crf} - i\% - 10) = \frac{\text{Col. 2 Col. 3}}{\text{Col. 4}} = \frac{(R_0 - R_1) + (M_0 - M_1)}{(I_1 - I_0)}$.

[b]Δ Num. = increment in Col. 5 between alternatives.
[c]Δ Denom. = increment in Col. 4 between alternatives.

[d]$\Delta \text{CRF} = \frac{\Delta \text{ Num.}}{\Delta \text{ Denom.}} = \frac{\text{Col. 9}}{\text{Col. 10}}$.

employed in the benefit-cost ratio method. (Again, the writer has elected to start with alternative D and work backward to A in order to simplify calculations.) For example, the consequence of selecting alternative D rather than "doing nothing" is to increase initial investment by $20,000 in order to receive a benefit of $2,690 each year for 10 years. Because the computed capital recovery factor (0.1345) is greater than that represented by the minimum attractive rate of return (0.1295), alternative D is acceptable.

The incremental effect of selecting alternative C rather than D is now examined. Although there will be no increase in initial costs, annual benefits will increase by $400 each year for 10 years. The incremental rate of return is therefore infinite. Continuing this pair-wise process until the last alternative has been considered, it is found that alternative A is the most economically feasible. (The actual rate of return on total investment for alternative A, found by reference to compound interest tables, is approximately 25%.) Of course, this is the same solution obtained by both the "excess of benefits over costs" and the benefit-cost ratio methods.

Example 2

Input Data.—The second example deals with six alternatives for a proposed highway facility. Data concerning road user costs, maintenance costs, initial investments, and estimated lives are given in Table 8. An interest rate of 5 percent is used. It is demonstrated in the following that the identical, correct solution may be obtained by using both the benefit-cost ratio and rate of return methods, and that the so-called "savings-cost ratio method" also yields a valid solution.

Benefit-Cost Ratio Method.—The results of the application of the benefit-cost ratio method are given in Table 9. It should be noted that the B/C values in Col. 6 erroneously indicate that alternative F is superior to the others. It is erroneous because the incremental analysis must be completed before being able to determine the most economical alternative.

The procedure outlined in Table 9 is identical with that used in Example 1 with one exception. In the preceding example it was fairly obvious that calculations could be minimized by starting with alternative D and working backward to A. Here it is not so readily evident; therefore, one begins with F and works down to K. By following the arithmetic, the procedure should be clear.

Another similarity to the preceding example is the generation of specious benefit-cost ratios (see Col. 11 for alternatives I, J, and K). For example, the choice of I rather than H results in a reduction in benefits of $9,774, but the associated cost reduction is only $7,402. Although the negative signs algebraically cancel each other, the resulting benefit-cost ratio should clearly be negative. One must be wary of blindly following rules of algebra without reference to common sense.

The benefit-cost ratio method indicates that alternative H is best. Referring again to the results of the "excess of benefits over costs" method—here given in Col. 7—H is

TABLE 8

EXAMPLE 2: INPUT DATA

Alt. (1)	$(R_0 - R_1)$ ($) (2)	$(M_0 - M_1)$ ($) (3)	$(I_1 - I_0)$ ($) (4)	n (yr) (5)
F	300	1,000	8,000	10
G	628	1,000	10,000	10
H	15,275	1,000	100,000	10
I	5,501	-4,000	10,000	50
J	4,188	-2,195	10,000	10
K	4,038	-1,055	10,000	5

TABLE 9

EXAMPLE 2: BENEFIT-COST RATIO SOLUTION

Alt. (1)	Benefit[a] ($) (2)	(crf - 5% - n) (3)	$(S_1 - S_0)$[b] ($) (4)	Cost[c] ($) (5)	B/C[d] ($) (6)	B-C[e] ($) (7)	Compare[f] (8)	Δ B ($) (9)	Δ C ($) (10)	Δ B:C (11)
F	300	0.1295	1,036	36	8.3	264	|F/ϕ|	300	36	8.3
G	628	0.1295	1,295	295	2.1	333	|G/F|	328	259	1.3
H	15,275	0.1295	12,950	11,950	1.3	3,325	|H/G|	14,647	11,650	1.3
I	5,501	0.0548	548	4,548	1.2	953	|I/H|	-9,774	-7,402	1.3[g]
J	4,188	0.1295	1,295	3,490	1.2	698	|J/H|	-11,087	-8,460	1.3[g]
K	4,038	0.2310	2,310	3,365	1.2	673	↓K/H↓	-11,237	-8,585	1.3[g]

[a] $(R_0 - R_1)$ = Col. 2, Table 8.
[b] $(S_1 - S_0) = (I_1 - I_0)$ (crf - 5% - n).
[c] Col. 4 - Col. 3, Table 8.
[d] Col. 2/Col. 5.
[e] Col. 2 - Col. 5.
[f] ϕ denotes the alternative "Do nothing, employ resources elsewhere."
[g] Actually, < 1.

seen to be superior to the other alternatives. This was predictable, of course, because the methods are equivalent.

Savings-Cost Ratio Method.—The author makes a distinction between the benefit-cost ratio and savings-cost ratio methods, although the writer pointed out in an earlier section that the only difference between these two methods is the location of maintenance costs in either the numerator or the denominator of the ratio, and the two methods will lead to identical solutions.

The writer's results using the savings-cost ratio solution are given in Table 10. (Again, the specious ratios shown for alternatives I, J, and K in Col. 8 should be noted.) The method used is identical to that shown in Table 9, except that the absolute values of the ratios are slightly different due to the location of maintenance costs in the numerator rather than in the denominator. The incremental analysis—beginning with F and working down through K—indicates that alternative H is the most economical. This checks with the results of the preceding section.

It is notable in passing that the absolute values of the benefit-cost ratios (Col. 6, Table 9) are neither equal to, nor provide the same ranking as, the computed savings-cost ratios (Col. 4, Table 10). This is not surprising, as the location of the maintenance costs has been shifted. However, the comparison is irrelevant inasmuch as (a) absolute values have no meaning when selecting among alternatives, and (b) only the incremental

TABLE 10

EXAMPLE 2: SAVINGS-COST RATIO SOLUTION

Alt. (1)	Cost[a] ($) (2)	Savings[b] ($) (3)	S/C[c] (4)	Compare (5)	Δ S ($) (6)	Δ C ($) (7)	Δ S/C (8)
F	1,036	1,300	1.3	|F/ϕ|	1,300	1,036	1.3
G	1,295	1,628	1.3	|G/F|	328	259	1.3
H	12,950	16,275	1.3	|H/G|	14,647	11,655	1.3
I	548	1,501	2.7	|I/H|	-14,774	-12,402	1.2[d]
J	1,295	1,993	1.5	|J/H|	-14,282	-11,655	1.2[d]
K	2,310	2,983	1.3	↓K/H↓	-13,292	-10,640	1.2[d]

[a] Col. 4, Table 9.
[b] Col. 2, Table 8 + Col. 3, Table 8.
[c] Col. 3/Col. 2.
[d] Actually, < 1.

analysis will yield the proper solution. (The statement about absolute values must be qualified. One needs only to determine if the ratio is greater than or less than unity. How much greater or how much less is irrelevant, all other factors being considered.)

Rate of Return Method. —Most of the calculations necessary for the rate of return solution are given in Table 11. As in the preceding benefit-cost and savings-cost solutions, the incremental analysis begins with F and works down through K. However, due to the difference in service lives of some of the alternatives, the method of calculating the incremental rates of return differs slightly from the procedure used in the first example.

The incremental rates of return for the pair-wise comparisons of F with "doing nothing," G with F, and H with G have been determined as in Example 1. This is possible because alternatives F, G, and H have equal lives (10 years); thus there is only one capital recovery factor in the solution equation, and it may be determined directly. Alternative I, however, has a life of 50 years, hence the solution equation for the differences between I and H is 0 = [100,000 (crf - i% - 10) - 16,275] - [10,000 (crf - i% - 50) - 1,501]. The unknown interest rate i may be determined by testing the equation using various values of i until the equality is satisfied. But, since the interest here is only in determining if the solving value for i is greater or less than 5%, one can simply substitute the appropriate capital recovery factors for i = 5% in this equation. Thus, [100,000 (crf - 5% - 10) - 16,275] - [10,000 (crf - 5% - 50) - 1,501] = [100,000 (0.1295) - 16,275] - [10,000 (0.0548) - 1,501] = [12,950 - 16,275] - [548 - 1,501] = -3,325 + 953 = -2,372. Because this value is negative, the solving rate of return must be less than 5%. Thus, alternative I is economically inferior to H and may be disregarded.

Alternative J may be compared to H as before, because each has a service life of 10 years. However, the resulting capital recovery factor is shown in parentheses in Col. 10, Table 11 because it is somewhat misleading. A $90,000 reduction in initial cost results in a reduction of $14,282 in operating and maintenance savings each year for 10 years. Thus the computed capital recovery factor (0.1587) is applicable to choosing H rather than J. (That is, if H is chosen rather than J the initial cost will be be increased by $90,000, but the annual operating and maintenance savings will be increased by $14,282.) Because the capital recovery factor for i = 5% and n = 10 is 0.1295, the rate of return for choosing H over J is greater than 5%. It follows that the rate of return for J over H is less than 5%.

Finally, alternative K must be compared with H, but the estimated service life for K is only 5 years. Thus i must be chosen so that the following equation is satisfied: 0 = [100,000 (crf - i% - 10) - 16,275] - [10,000 (crf - i% - 5) - 2,983]. Substituting i = 5% gives [100,000 (crf - 5% - 10) - 16,275] - [10,000 (crf - 5% - 5) - 2,983] = [100,000 (0.1295) - 16,275] - [10,000 (0.2310) - 2,983] = [12,950 - 16,275] - [2,310 - 2,983] = -3,325 + 673 = -2,652. Again, because the solution is a negative value, it is

TABLE 11

EXAMPLE 2: RATE OF RETURN SOLUTION

Alt. (1)	$(I_1 - I_0)$ ($) (2)	Ann. Sav.[a] ($) (3)	n (yr) (4)	CRF[b] (5)	i% (6)	Compare (7)	Δ Col. 2 ($) (8)	Δ Col. 3 ($) (9)	Δ CRF[c] (10)	Δ i% (11)
F	8,000	1,300	10	0.1628	10	|F/ϕ|	8,000	1,300	0.1625	10
G	10,000	1,628	10	0.1628	10	|G/F|	2,000	328	0.1640	10
H	100,000	16,275	10	0.1628	10	|H/G|	90,000	14,647	0.1627	10
I	10,000	1,501	50	0.1501	15	|I/H|	-d	-d	-d	<5
J	10,000	1,993	10	0.1993	15	|J/H|	-90,000	-14,282	(0.1587)	<5
K	10,000	2,983	5	0.2983	15	↓K/H↓	-d	-d	-d	<5

[a]Annual savings resulting from investment (Col. 3, Table 10).

[b]$CRF = (crf - i\% - n) = \frac{(R_0 - R_1) + (M_0 - M_1)}{(I_1 - I_0)}$.

[c]Δ CRF = Col. 9/Col. 8.

[d]See text for discussion of special form of analysis.

concluded that the true rate of return of the increment is less than 5%. Hence alternative H is superior to all others being considered in the problem. (This is the same solution, of course, which was obtained by the other methods.)

Example 3

Problem Statement.—The author presented a third example using only the rate of return method. He said: "Although the rate of return method can be more complex computationally, proper evaluation of the usually large capital expenditures for proposed public facilities compensates many times over for the extra effort. Example 3 demonstrates that even the more complex problems require only added computational time." It is demonstrated in the following that the benefit-cost ratio method will also lead to a "proper evaluation."

This problem deals with a proposed relocation of an existing highway. The basic data are as follows:

Item	First Cost ($)	Service Life (yr)
Right-of-way	50,000	60
Grading and drainage	200,000	40
Paving	100,000	20
Roadway rehabilitation	40,000	10

Further, adoption of the new location is expected to decrease road user costs by $92,000 per year and increase maintenance costs by $20,000 per year. Two alternatives are involved—do nothing or relocate the highway.

Rate of Return Method.—The rate of return on the proposed investment is that value of i which satisfies the equation: 50,000 (crf - i% - 60) + 200,000 (crf - i% - 40) + 100,000 (crf - i% - 20) + 40,000 (sff - i% - 10) - 92,000 + 20,000 = 0. Wherein (sff - i% - 10) is the mnemonic form of the "sinking fund factor" for i = 10% and n = 10.

One would normally begin a trial-and-error procedure until the appropriate i is found (in this case about 20%). This is verified as follows, using i = 20%: 50,000 (crf - 20% - 60) + 200,000 (crf - 20% - 40) + 100,000 (crf - 20% - 20) + 40,000 (sff - 20% - 10) - 92,000 + 20,000 = 50,000 (0.20001) + 200,000 (0.20014) + 100,000 (0.20536) + 40,000 (0.03852) - 92,000 + 20,000 = 105 (or almost 0).

The analysis is not complete, however. It is still not known whether or not the proposal should be accepted. To do so, the project rate of return must be compared with that available by investing elsewhere, usually stated as the "minimum attractive rate of return." In Examples 1 and 2 this value was given as 5%. Assuming that the same value applies to this problem, it is now possible to state that relocation of the highway is preferable to doing nothing; that is, the funds invested in the new facility will yield 20%, which is greater than the expected return from other potential (but unknown) investments.

Benefit-Cost Ratio Method.—Using an interest rate of 5%, the first step is to convert all consequences of the proposal to uniform annual series. The consequences are then assigned to "benefits" or "costs" and the benefit-cost ratio is computed. (The computations are fairly simple in this example because only two alternatives are being considered. The complex incremental technique is necessary only when there are three or more alternatives.)

$$(R_0 - R_1) = \$92,000$$

$$\begin{aligned} \$\,50,000\ (crf - 5\% - 60) &= 50,000\ (0.05283) = 2,642 \\ 200,000\ (crf - 5\% - 40) &= 200,000\ (0.05828) = 11,656 \\ 100,000\ (crf - 5\% - 20) &= 100,000\ (0.08024) = 8,024 \\ 40,000\ (sff - 5\% - 10) &= 40,000\ (0.07950) = 3,180 \\ (S_1 - S_0) &= \$25,502 \end{aligned}$$

$$(M_1 - M_0) = \$20,000$$

$$B/C = \frac{(R_0 - R_1)}{(S_1 - S_0) + (M_1 - M_0)} = \frac{\$92,000}{\$25,502 + \$20,000} = 2.0$$

Because the resulting benefit-cost ratio is greater than unity, the new proposal should be accepted. Moreover, the savings-cost ratio method yields the same solution:

$$S/C = \frac{(R_0 - R_1) - (M_1 - M_0)}{(S_1 - S_0)} = \frac{\$92,000 - \$20,000}{\$25,502} = 2.8$$

It is emphasized again that although the absolute values of the two ratios may differ the same course of action is indicated because each ratio is greater than unity.

Summary

In addition to demonstrating the techniques of incremental analysis, the objective of this discussion is to show the equivalence of various analytical methods. The examples used by Professor Smith to show "three crucial defects in the benefit-cost ratio method" have been re-analyzed here to illustrate that these so-called defects are matters of procedural error rather than inherent invalidity. Moreover, it has been shown that the differences between the benefit-cost ratio and savings-cost ratio methods are effectively inconsequential.

Although the "excess of benefits over costs," benefit-cost ratio, savings-cost ratio, and rate of return methods are equivalent insofar as they lead to the correct choice among alternative investment proposals, it is not meant to imply that each of them is equally effective as a practical analytical tool. Certainly the author and the writer agree on this point. In fact, the writer views the benefit-cost ratio method (and other such methods based on a ratio) with considerable disfavor. However, since the purpose here is simply to discuss validity and not relative efficacy, the question of choice of method is left to another time and place.

GERALD W. SMITH, Closure—The paper is concerned with exceptions to a general (benefit-cost ratio) approach to problems. Its object is to illustrate that sometimes the general rule is imperfect. To argue such an exception is more difficult, for the argument must show that all of the supposed exceptions are untrue (otherwise, exceptions still exist).

As in most questions, the opinion differences between author and discussers arise from differences in assumptions. The paper treats sets of alternatives (a) without restriction as to whether alternatives are mutually exclusive or non-mutually exclusive, and (b) without restriction as to the "cut-off" or "minimum acceptable" benefit-cost ratio used by the analyst.

The comments are appropriate only when all of three conditions are met: (1) the alternatives are mutually exclusive, (2) the analyst using the benefit-cost ratio technique applies a cut-off of minimum acceptable benefit-cost ratio of 1.0, and (3) when it is reasonable for the analyst using a minimum acceptable ratio of, say 2.0, coupled with an interest rate of, say 5%, to change his method so that he now applies a minimum acceptable ratio of 1.0 and an interest rate of 5%.

A question is raised here: is there a variety of minimum acceptable benefit-cost ratios, other than 1.0, in use? The widely used AASHO report (1) does not suggest use of the 1.0 minimum acceptable ratio, even in the "second benefit" incremental approach presented on page 151. It is on this basis that the paper leaves unrestricted the question of what minimum acceptable benefit-cost ratio will be used by the analyst.

The conclusions which may be drawn from the paper and comments as a total seem to be:

1. If alternatives are non-mutually exclusive and if a minimum acceptable ratio other than 1.0 is used, the benefit-cost ratio can lead to erroneous conclusions.

2. If alternatives are non-mutually exclusive and if a minimum acceptable ratio of 1.0 is used, the benefit-cost ratio can lead to erroneous conclusions.

3. If alternatives are mutually exclusive and if a minimum acceptable ratio other than 1.0 is used, the benefit-cost ratio can lead to erroneous conclusions.

4. If alternatives are mutually exclusive, and if a minimum acceptable ratio of 1.0 is used, and if it is reasonable to use a ratio of 1.0 coupled with an interest rate of 5%, instead of some other ratio, perhaps 2.0, coupled with an interest rate of 5%, the incremental benefit-cost approach illustrated in the comments can be applied as shown to yield correct conclusions.

The divergence of approach is not as great as it might appear. This may be illustrated by Example 6, pages 40-44 of the AASHO report (1). The conclusion (p. 44) that "Plan 1 is more desirable than Plan 2" is questionable. Both parties agree that the question is one of interpretation, that a benefit-cost ratio for Plan 1 of 5.16 and a benefit-cost ratio for Plan 2 of 4.75 does not necessarily mean that Plan 1 is better than Plan 2 if the plans are mutually exclusive. Both parties agree that supplementary rate of return analyses (incremental if appropriate) would help the analyst avoid erroneous conclusions.

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

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

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:

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

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,

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

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 × 0.350344 + \$40,000 × 0.12274 - (1 - 4/18) \$40,000 × 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.

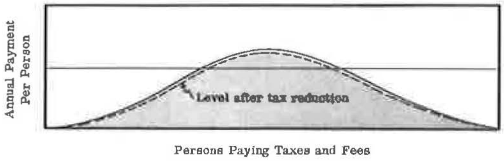

Figure 1. Idealized distribution of financial support for public highways, streets, and roads.

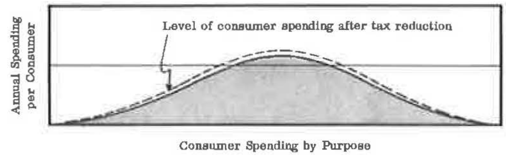

Figure 2. Idealized distribution of consumer spending by purpose.

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

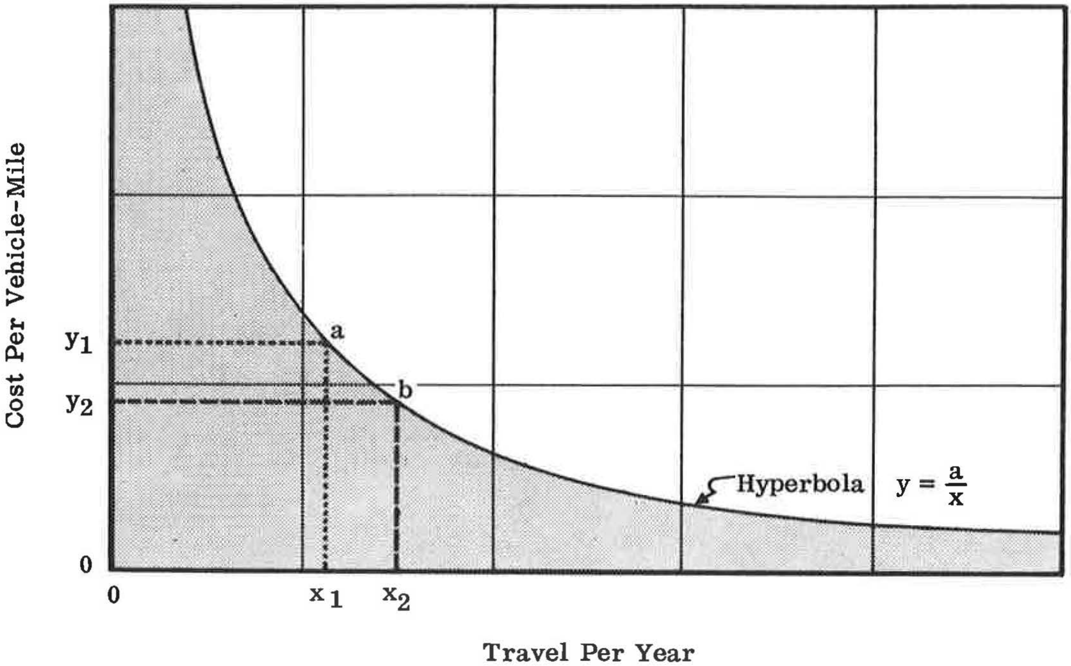

Figure 3. Changes in travel due to changes in unit vehicle cost.

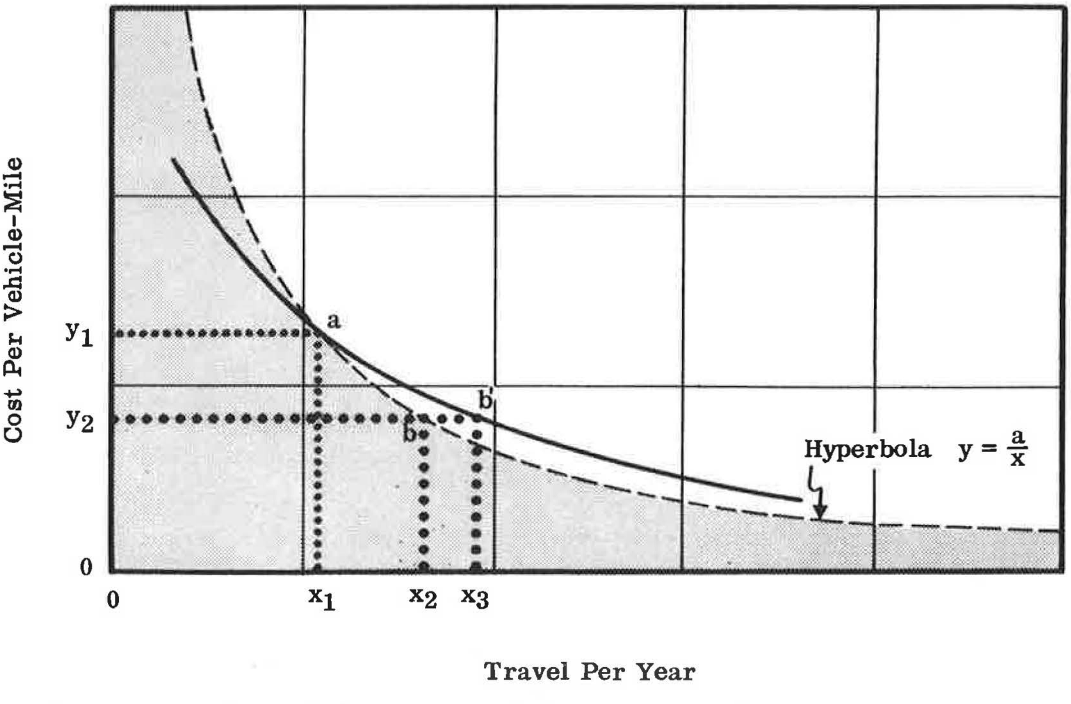

Figure 4. Changes in travel due to changes in unit vehicle cost.

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.

Programing Highway Accident Reduction

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•THE HIGHWAY accident analyses reported in this paper were undertaken to determine the degree to which the incidence of accidents is influenced by the level of adequacy of highways. It was accomplished in connection with the highway needs and planning studies in the States of Kansas, South Dakota and Kentucky. Answers were sought to such questions as whether a modern highway is safer than one that has deficiencies in its geometric and structural features, and if it is, how much safer.

In evaluating highway needs, and in recommending improvement programs, providing safety for the highway users assumes paramount importance. The studies in Kansas, South Dakota, and Kentucky had as a basic objective the creation of a continuing long-range plan for raising the service adequacy of the roads and streets to a level that provides efficiency and safety. There are guidelines available through established and widely accepted geometric and structural standards. And, the long-range plans are developed to meet these standards. There are, however, no definitive measures of what application of these standards will produce in the way of added safety, except for freeways—controlled-access highways.

(In addition to the value of having a broad appraisal of safety associated with highway improvements, there also is a potential in this kind of research to provide basic data for more effective analysis of accident hazards at spot locations. Rudy (1) pointed out limitations of previous spot location studies due to the difficulty of differentiating between accidents caused by chance and those caused by highway hazards. This has caused a situation in which most actual investigation of hazardous locations results from requests of the public or outside agencies instead of from analysis of accident records. This, he said, is somewhat of an indictment. The paper contains a technique for using statistical probability analysis to determine accidents caused by chance. It appears to be a workable technique and one which can be further enhanced by the type of research performed in Kansas, South Dakota, and Kentucky through development of average or mean occurrences in situations controlled by such things as roadway geometrics or structural conditions.)

Because the safety record in freeways has been so striking in contrast with conventional highways, and because accident records have been analyzed to provide direct comparisons, the safety associated with programs for freeways is well-established and represents an important reason for the support of highway modernization involving such highways. Rapid development of the Interstate System is justified to a great degree by the accidents it will eliminate and the lives it will save.

Figure 1 shows the potential for accident reduction on the Interstate System in Kansas. The accident rate on conventional highways serving the same traffic before Interstate construction is compared with the rate on the Interstate. Here then, clear evidence is provided of the safety of modern highways when these highways are freeways—controlled-access facilities.

It was recognized that freeways represent a special case and that the great mileages of other types of highway would not be at all comparable to freeways, in the contrast between existing low-standard facilities and new construction. In fact, up to this time, limited observations and the judgments of some highway engineers have left a question as to whether modernization was not increasing rather than decreasing the incidence of accidents.

Paper sponsored by Committee on Highway Costs.

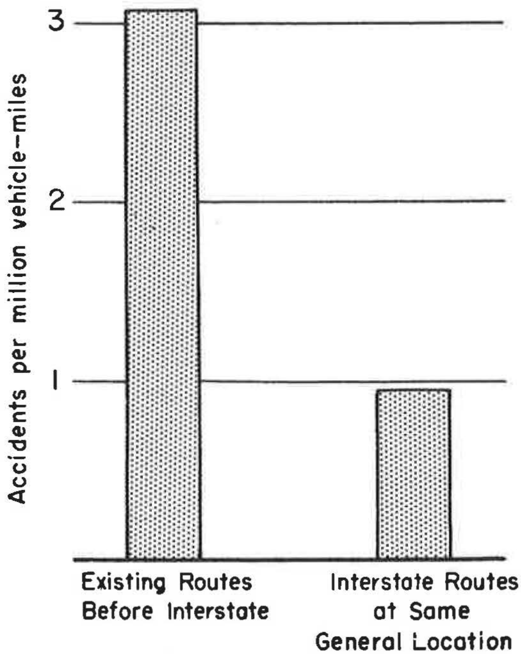

Figure 1. Accident rate comparison before and after Interstate construction, Kansas.

In undertaking this study, it was recognized that it would probably be necessary to accumulate large quantities of accident data and to group road sections of comparable service adequacy level in order to obtain a correlation between accidents and the level of improvement. The recorded accident data and the sufficiency ratings in the three States appeared well adapted to this kind of analysis.

In all three States, accidents on State highways are spotted on county maps by calendar year and can be summarized for specific road sections. Also, in these States sufficiency ratings have been made on rural State highways. These ratings reflect the geometric and structural adequacy of road sections against a rating scale of 100. Therefore, accidents occurring on road sections in a particular year can be counted, and the sufficiency rating for the same section reflects its adequacy—the degree to which the section meets fully adequate improvement standards.

In setting up the analysis in each State it was necessary to limit the number of years covered up to those in which both accidents and ratings for the year were available.

In the Kansas analysis, it was possible to use data for accidents occurring during the years 1956, 1958, 1959, 1960, and 1961. In total, over these years, there were 32,436 accidents included in the analysis. These accidents occurred on approximately 8,900 miles of rural State highways. There were 1,069 fatal accidents causing 1,381 deaths. Accidents causing personal injuries numbered 10,621, and the injuries were sustained by 19,413 persons. There were 20,746 accidents causing property damage only.

In South Dakota, accident data for rural State highways were used for two years—1960 and 1961. There were 4,126 accidents included in the analysis—207 of them fatal and 1,540 causing personal injuries. There were 261 persons killed and 3,034 persons injured. Summaries of the basic data analyzed in Kansas and South Dakota, broken down by years, are given in Tables 1 and 2.

The Kentucky data are not used in this report except for one illustration. Though generally indicating the same results as Kansas and South Dakota data, the correlations in Kentucky suffered from a shorter experience period (one year) and from limitations in associated data. Because departures from the Kansas and South Dakota results were found to be inconsistent in themselves when subjected to different analyses and breakdowns of data, illustrative material from Kentucky neither adds to nor detracts from consistent findings in the other two States. It is anticipated, however, that Kentucky will continue its analysis and make a worthwhile contribution to research in this area as time goes on and more data are obtained.

A tabulating punch card was prepared for each road section for each year included in the analysis. The cards contained summaries of accidents and information on road section identification, length, sufficiency rating, traffic volume group, and vehicle-miles for the year of record. No cards were made up for years when construction was under way, or other occurrences distorted the traffic picture or the physical make-up of the road section.

These tabulating punch cards were processed in several ways. The simplest correlation developed was the incidence of accidents on highways in different sufficiency

TABLE 1

SUMMARY OF DATA ANALYZED
KANSAS

Year	Miles of Highway	Veh-Mi/Day (× 1,000)	Accidents		Fatalities	
			Total	Per Million Veh-Mi	Total	Per 100 Million Veh-Mi
1956	9,170	11,723	7,909	1.85	399	9.35
1958	9,173	11,146	7,460	1.83	251	6.17
1959	8,828	9,942	6,417	1.77	251	6.92
1960	8,657	9,501	5,810	1.68	247	7.12
1961	8,798	9,731	4,840	1.36	233	6.56
Avg.	8,925	10,409	6,485	1.71	276	7.27

TABLE 2

SUMMARY OF DATA ANALYZED
SOUTH DAKOTA

Year	Miles of Highway	Veh-Mi/Day (× 1,000)	Accidents		Fatalities	
			Total	Per Million Veh-Mi	Total	Per 100 Million Veh-Mi
1960	6,849	5,293	2,042	1.06	145	7.51
1961	6,906	5,350	2,084	1.07	116	5.93
Avg.	6,878	5,321	2,063	1.06	131	6.72

rating groups. The results obtained in Kansas and South Dakota are shown in Figures 2 and 3. In the calculations for these charts, accidents and vehicle-miles were added for each rating group without regard to character of accident or volume of traffic in order to establish the incidence for the group. The grand totals of accidents and vehicle-miles for all rating groups provide an overall average for comparison purposes. Accident rates are expressed as the number of accidents occurring per million vehicle-miles of travel.

There is apparent from the charts a marked reduction in the accident rate from the poorest highways (rating less than 50) to the best highway rating 80 and over.

The marked difference between the average accident rates in Kansas (1.71) and South Dakota (1.06) may be, in part, a reflection of broader report coverage in Kansas. Although both States have the same legal requirements for reporting, Tables 1 and 2 show that the ratio of fatal accidents to total reported accidents is 1 to 30 in Kansas and 1 to 20 in South Dakota.

Although similar results were obtained in Kentucky, the trend in accident reduction for increases in sufficiency rating was not, by any means, smooth. One factor appearing to have considerable effect in this State was the short length of many sufficiency rating sections. Indications were that a disproportionate number of accidents occurred on short sections of highway (less than five miles in length) having a relatively high standard of adequacy. At any rate, eliminating these sections in the 80 to 100 sufficiency rating group and comparing the accident rate on the remaining longer stretches of highway (over five miles in length) with the average rate for all State highways produced the results shown in Figure 4. (Another problem affecting the Kentucky results, which also may have had considerable significance in the foregoing, was the difficulty of accurately spotting accidents on the proper highway sections due to differences between reports for the same accident.)

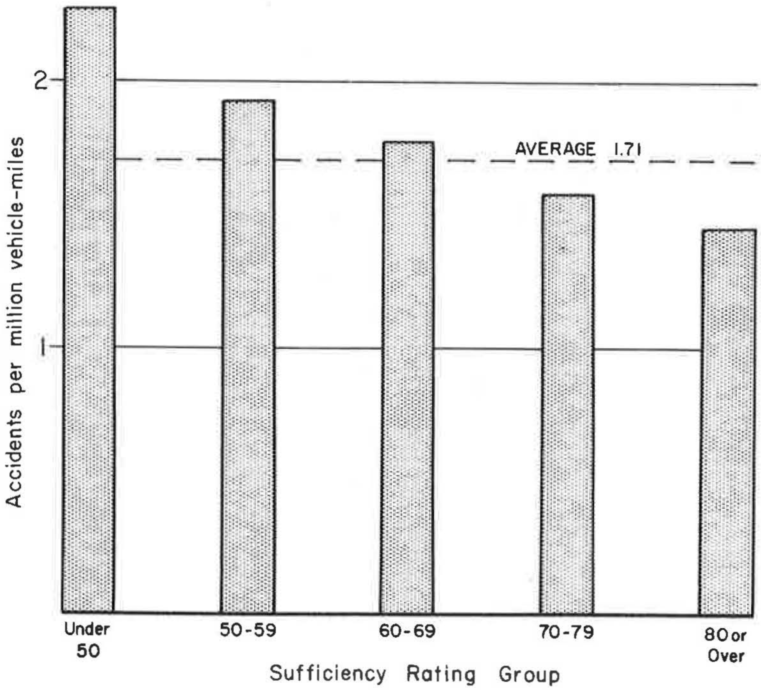

Figure 2. Accident rates, rural State highways, Kansas.

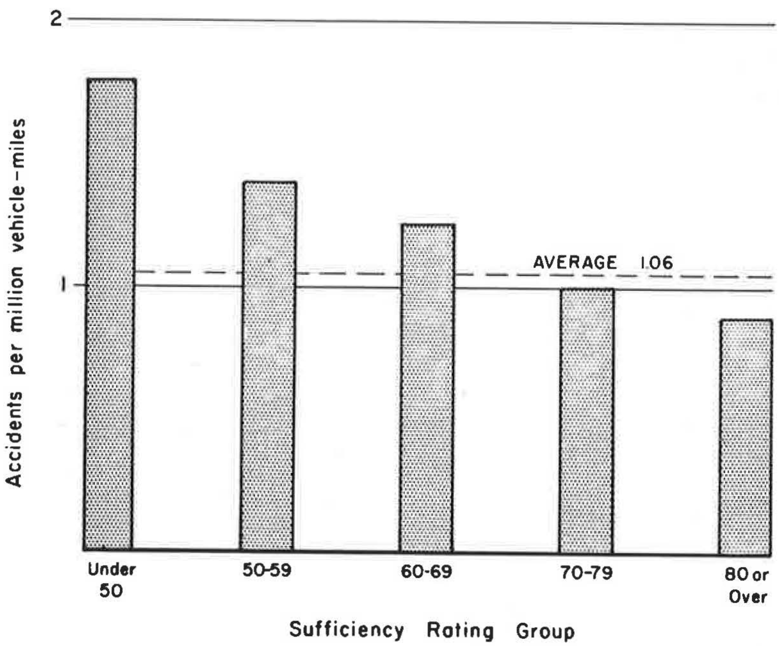

Figure 3. Accident rates, rural State trunk highways, South Dakota.

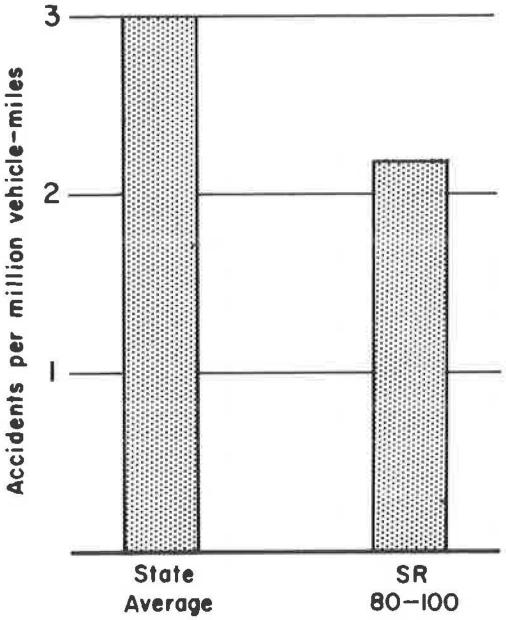

Figure 4. Accident rate comparison between State average and improved highways, Kentucky.

With the recognition that relative traffic volumes in themselves probably are a major factor in the incidence of accidents, correlations were made in all three States of accident rates by sufficiency rating within each traffic volume group. Once more, the Kentucky results showed the expected trends but were inconclusive. However, the Kansas and South Dakota results (Figs. 5 and 6) produced sufficiently clear patterns in both cases to support the following conclusions:

1. Accidents are reduced in all traffic volume groups by improving highways to more adequate standards.
2. Accident rates increase as traffic volume increases in most sufficiency rating groups.

With respect to the latter conclusion, an apparent conflict is in the results obtained in the two States on highways developed to, or close to, fully modern standards for the traffic they carry (sufficiency ratings 80 to 100). The South Dakota analysis indicates that accident rates on these highways are not greatly influenced by the volume of traffic. On the other hand, the Kansas analysis generally indicates that larger volumes of traffic bring increases in

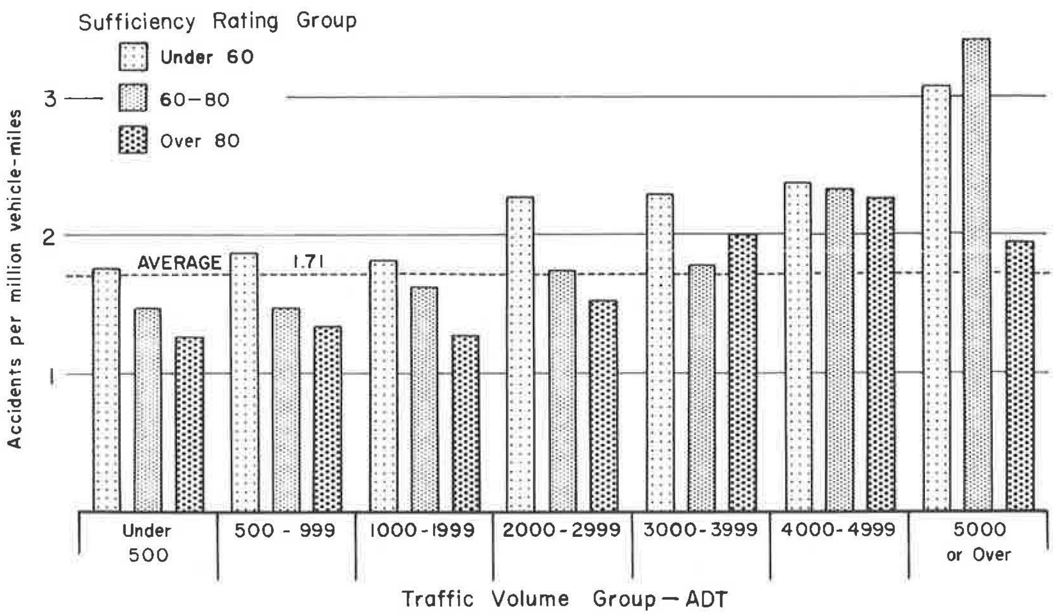

Figure 5. Accident rates by sufficiency rating and traffic volume groups, rural State highways, Kansas.

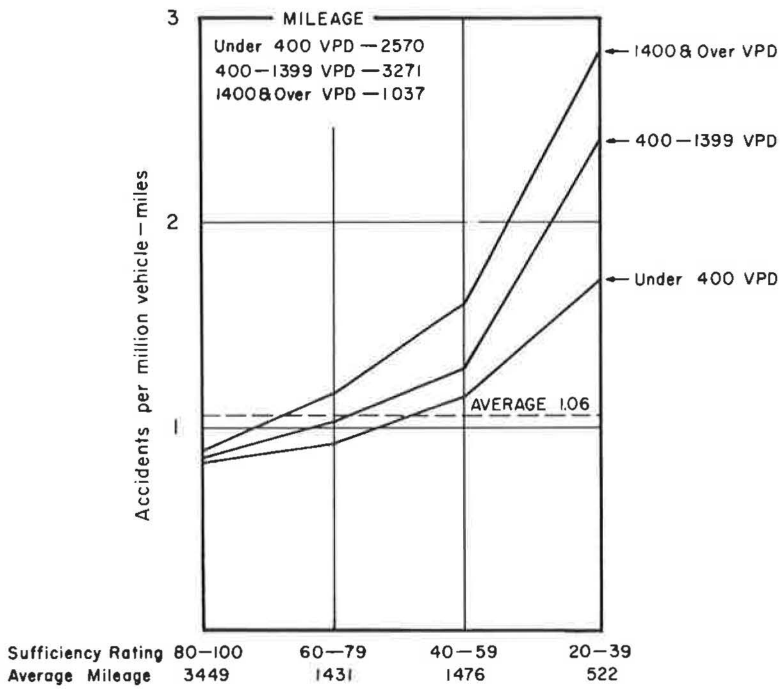

Figure 6. Accident rates by sufficiency rating and traffic volume groups, rural State trunk highways, South Dakota.

accidents regardless of whether highways in Kansas are operating nearer capacity than those in South Dakota.

Thorough evaluation of factors like this was not within the scope of the limited studies performed in connection with the highway needs determinations, nor were there any attempts mathematically to determine regressions and correlations. There also were limitations in currently available data in all cases. Some of the following undoubtedly account for discrepancies in trends and patterns:

1. Relatively small road mileages and/or total vehicle-miles of travel as represented in some sufficiency rating and traffic volume groups did not provide a basis for statistically sound comparisons.
2. Historical sufficiency ratings used to indicate basic road characteristics did not include evaluations of some significant road elements. For example, none of the sufficiency rating methods took capacity into account; only one took both gradients and curvature into consideration.

Most of these problems should be eliminated with more accident history, better reporting procedures, and amended sufficiency rating methods; the last can be made rather easily to reflect all important roadway characteristics.

In regard to the strong indication (Figs. 5 and 6) that accident rates are affected significantly by volumes of traffic alone (the commonly-accepted concept that an exposure factor should be applied in analyses of this type), correlations were made between accidents and traffic volumes without relation to sufficiency ratings. Results for Kansas are shown in Figure 7.

In South Dakota, data also were processed to show the relationship between accidents and surface widths, as shown in Figure 8.

Relationships between types of accidents and road adequacy were studied, with results as shown in Figures 9 and 10. Although the South Dakota data, assembled for two years only, do not represent a sufficient number of fatal accidents for conclusive

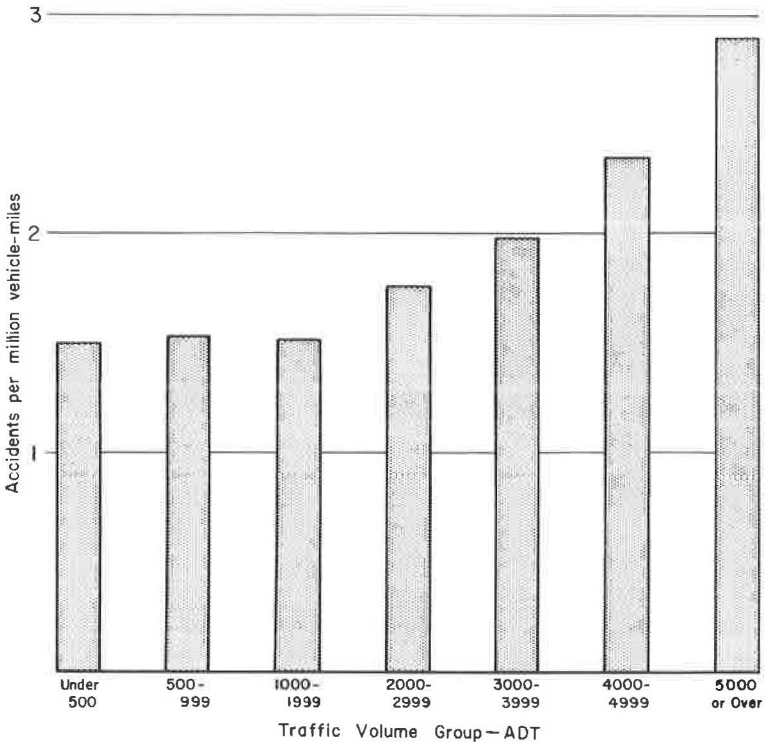

Figure 7. Accident rates by traffic volume groups, Kansas.

findings, there is considerable similarity in the pattern of fatal accident incidence for the two States. The most significant conclusion that can be drawn from this part of the analyses is that the severity of accidents is greater on higher standard roads because, even though there is a lower incidence rate for accidents, the fatality rate does not show a parallel reduction.

In Kansas, a further correlation was made between accidents occurring in different sections of the State as represented by the highway divisions and the weighted average sufficiency ratings of highways in these divisions. The results (Fig. 11) once more show the very marked influence of road adequacy on accident rates.

As a kind of bridge between the studies of the significance of road adequacy and traffic volumes in influencing accident rates and an economic evaluation of the results, the question was raised of how many accidents could be prevented by improving all roads to different minimum sufficiency ratings. This was answered by determining the average accident rate

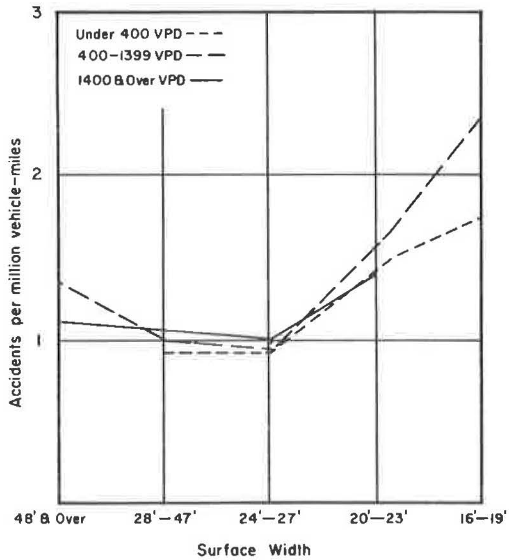

Figure 8. Comparison of accident rates and surface widths, South Dakota.

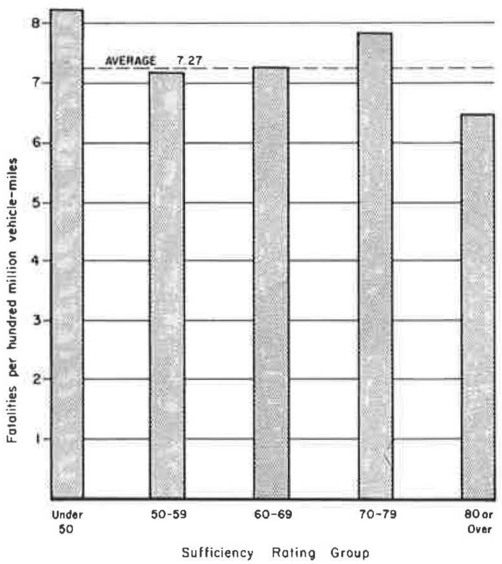

Figure 9. Fatality rates, rural State highways, Kansas.

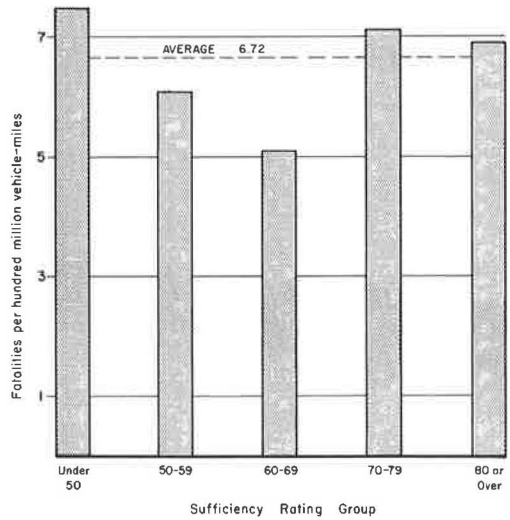

Figure 10. Fatality rates, rural State trunk highways, South Dakota.

over various sufficiency rating cutoff values—assuming present distributions of traffic—and by applying this rate, in each case, to all of the vehicle-miles traveled on the highway system. The details of this determination for Kansas are given in Table 3 and Figure 12.

A similar analysis was made in South Dakota on a slightly different basis, and economic loss values of accidents were applied as determined from the National Safety

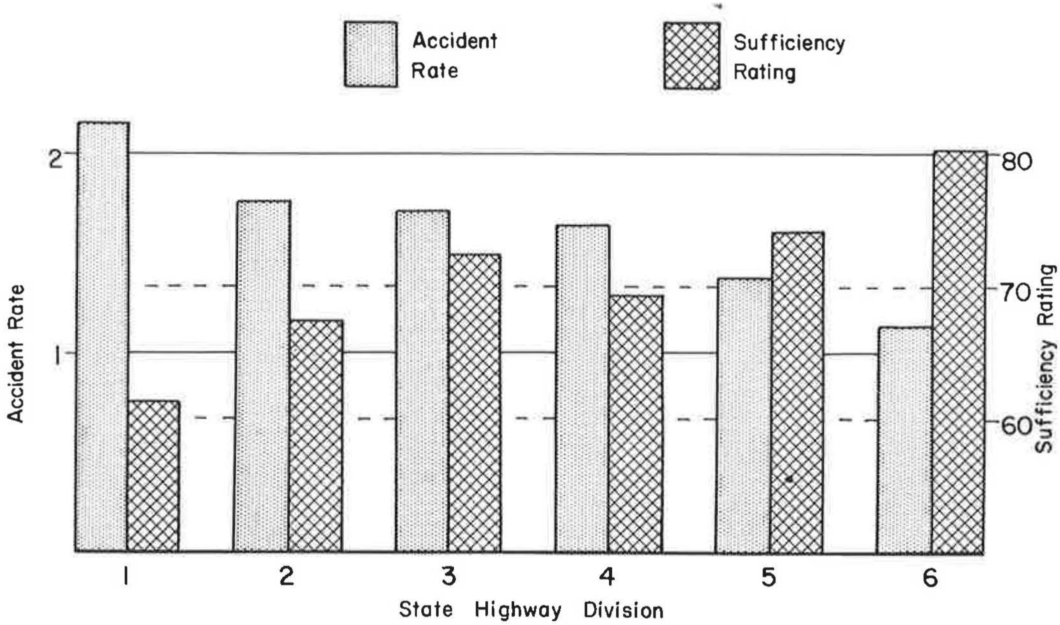

Figure 11. Comparison of accident rates and sufficiency ratings, Kansas.

TABLE 3

POTENTIAL ACCIDENT REDUCTION FROM HIGHWAY IMPROVEMENTS[1]
KANSAS

Sufficiency Rating Group	1956-61 Veh-mi per day (× 1,000)	1956-61 Accidents	Avg. Rate	Avg. Rate × 1961 Traffic[2]	Reduction
All	52,043	32,436	1.71	8,040	-
50 - 100	46,406	27,747	1.64	7,711	329
60 - 100	38,493	22,185	1.58	7,429	611
70 - 100	28,607	15,773	1.51	7,100	940
80 - 100	17,745	9,475	1.46	6,865	1,175

[1] 1956-61 average rates applied to 1961 traffic.
[2] Based on 4,702 million vehicle-miles on rural State highways in 1961. Represents number of accidents obtained by multiplying 4,702 by accident rate appropriate to SR group. Potential accident reduction obtained by subtracting result from 8,040.

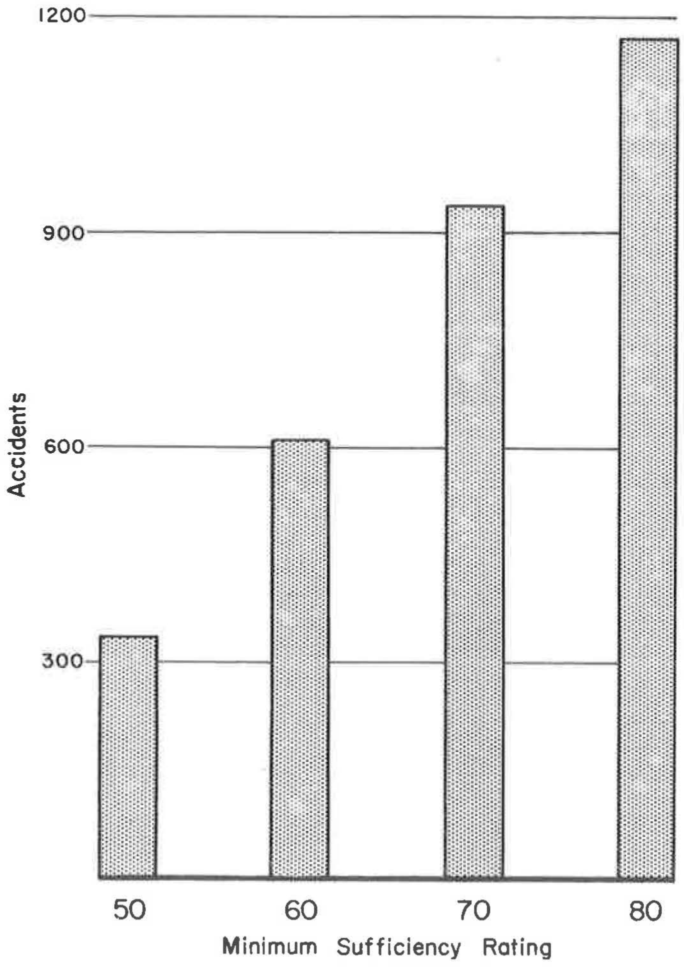

Figure 12. Potential annual accident reduction, rural State highways, Kansas.

TABLE 4

POTENTIAL ECONOMIC SAVINGS FROM HIGHWAY IMPROVEMENTS THROUGH REDUCTION IN ACCIDENTS
SOUTH DAKOTA[a]
FIRST METHOD

Sufficiency Rating Group	Miles of Highway	Avg. Annual Total Loss (x $100)	Avg. Annual VM Travel (x 100)	Avg. Annual Econ. Loss per Veh-Mi	Avg. Annual Veh-Mi of Highway	Avg. Annual Loss/Mi of Highway ($)	Avg. Annual Loss/Mi After Improvement ($)	Avg. Annual Savings[b] Mi of Improved Highway ($)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Under 60	1,998.3[1]	18,366	3,544,548	0.0052	177,379	922	727	195[1]
60 - 69	559.4[2]	8,406	1,836,339	0.0046	328,298	1,510	1,346	164[2]
70 - 79	871.4	15,540	3,554,757	0.0044	407,926	1,795	1,673	122
80 - 100	3,449.2	42,778	10,487,757	0.0041	304,060	1,247	1,247	-
Method		From data sheets (avg. of 1960, 1961 records)		Col. 3 / Col. 4	Col. 4 / Col. 2	Col. 5 × Col. 6	0.0041 × Col. 6	Col. 7 - Col. 8

[a]Based on 1960-61 data.

[b]Computation of annual savings by improving miles below SR 70:

[1]1,998 miles at $195 = $389,610
[2]559 miles at $164 = $ 91,676
Total annual savings = $481,286

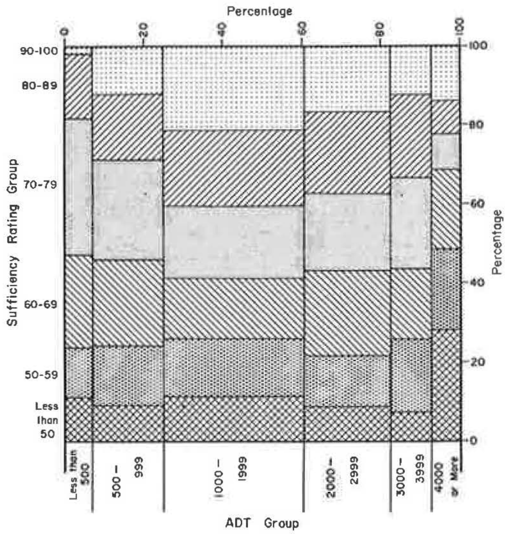

Figure 13. Distribution of vehicle-miles, rural State highways, Kansas.

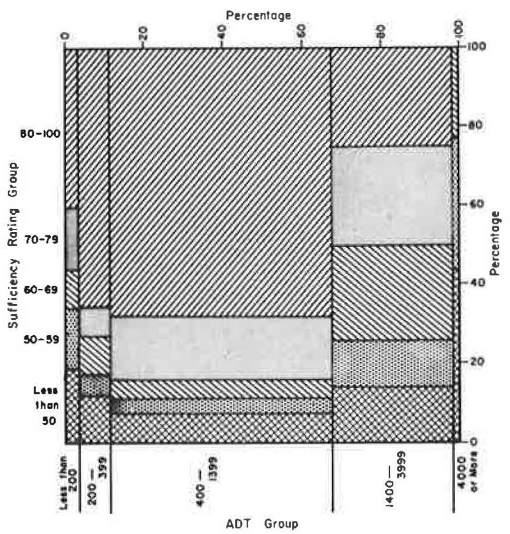

Figure 14. Distribution of vehicle-miles, rural State trunk highways, South Dakota.

Council's 1961 estimate rates. The details of this application are given in Table 4.

In this case, the assumption was made that all mileage under sufficiency rating 70 would be improved through construction to the 80 to 100 sufficiency rating category. The average annual economic loss per vehicle-mile for this category ($0.0041) was applied to the vehicle-miles presently under 70, and a comparison was made with the economic loss on the unimproved mileage ($0.0052 and $0.0046, as given in the table). The results were related to the miles of highway assumed to be improved, and annual savings were calculated.

This simple application of average economic losses (derived by totaling types of accidents in the sufficiency rating groups, applying estimated costs for the respective types, and dividing the total resulting cost by vehicle-miles) neglects the possible effect of relatively different traffic volumes within the sufficiency rating groups, as sum-

TABLE 5

DISTRIBUTION OF VEHICLE-MILES
KANSAS

Sufficiency Rating Group	Vehicle-Mile Distribution per Day						
	Less than 500,000 Veh-Mi	500,000-999,000 Veh-Mi	1,000,000-1,999,000 Veh-Mi	2,000,000-2,999,000 Veh-Mi	3,000,000-3,999,000 Veh-Mi	4,000,000-or More Veh-Mi	Total All ADT Groups
90 - 100	16	229	797	384	132	108	1,666
80 - 89	122	311	690	464	230	65	1,882
70 - 79	264	467	686	444	246	65	2,172
60 - 69	179	407	547	488	196	161	1,978
50 - 59	94	284	549	301	200	156	1,584
Less than 50	84	163	400	188	76	216	1,127
Total	759	1,861	3,669	2,269	1,080	779	10,409

TABLE 6

DISTRIBUTION OF VEHICLE-MILES
SOUTH DAKOTA

Sufficiency Rating Group	Vehicle-Mile Distribution per Day					
	Less than 200,000 Veh-Mi	200,000-399,000 Veh-Mi	400,000-1,399,000 Veh-Mi	1,400,000-3,999,000 Veh-Mi	4,000,000 or More Veh-Mi	Total All ADT Groups
80 - 100	70	279	2,027	426	21	2,823
70 - 79	29	32	480	412	-	953
60 - 69	16	39	150	406	-	611
50 - 59	27	24	115	212	30	408
Less than 50	31	47	198	212	38	526
Total	173	421	2,970	1,668	89	5,321

TABLE 7

POTENTIAL ECONOMIC SAVINGS FROM HIGHWAY IMPROVEMENTS THROUGH REDUCTION IN ACCIDENTS
SOUTH DAKOTA[1]
SECOND METHOD

ADT	SR Group	Economic Loss per 1,000 Veh-Mi ($)	Annual Vehicle Miles under 70 (x 1,000)	Annual Total Accident Cost ($)	Savings[2] ($)
Under 400	Under 70	4.13	92,818	383,338.34	-9,281.80
	80 - 100	4.23	92,818	392,620.14	
400 - 1,400	Under 70	4.76	212,136	1,009,767.36	212,136.00
	80 - 100	3.76	212,136	797,631.36	
Over 1,400	Under 70	5.52	233,124	1,286,844.48	160,855.56
	80 - 100	4.83	233,124	1,125,988.92	
Total					363,709.76

[1]Based on 1960-61 data. [2]Difference between first (under 70) SR group and second (80 - 100).

TABLE 8

ACCIDENT COST REDUCTION, KANSAS, 1961

Accident Category	Number per Accident	Annual Reduction	Annual Savings per Accident ($)	Total Annual Savings ($)
Fatalities	0.0426	40	31,500	1,260,000
Injuries	0.5990	563	1,750	1,050,000
Property damage	-	940	300	282,000
Total				2,592,000

marized in Tables 5 and 6 and shown in Figures 13 and 14. As already indicated, volumes of traffic in themselves influence the accident rates.

For this reason, further analyses were made by individual traffic volume groups to verify the potential savings through accident reduction by improving all highways below a given adequacy or sufficiency rating level. The methodology and results are given in Table 7 for basically the same data used in Table 4. (In line with the basic assumption that only the mileage below 70 would be improved, the economic losses in the 70 to 79 group did not affect the calculations in either Table 4 or Table 7 analysis, although these losses are shown in the former table.)

In Kansas, the approximate annual reduction in accident cost that could be effected by raising all highways to sufficiency rating 70 was determined simply by calculating the average number of fatalities and personal injuries per accident, and the average amount of property damage per accident, from the 1956-1961 data, and by applying these incidences to the number of accident reductions from Table 3 (940). The results, as calculated for 1961, are given in Table 8.

Proceeding from these determinations, it is possible by projecting traffic to calculate the potential savings through construction performed over any future program period, if the objective of the program is to raise all highways to a minimum level of adequacy.

In reviewing what has been done in the analyses here reported, the following are apparent:

1. Positive safety values of considerable magnitude associated with raising the adequacy level of rural State highways.
2. Potentiality for further research exploitation of the massive amount of data on accidents which can be tied to road adequacy rating data and specific highway elements.
3. An opportunity ultimately to reflect the value of highway modernization in specific and authoritative terms showing savings in lives, injuries, and property damage.

ACKNOWLEDGMENTS

Although Roy Jorgensen and Associates, as consultants, were responsible for the highway needs and planning studies, and for guidance of associated research, the accident analyses were performed by State personnel under the direction of Robert Willis, Kansas; C.P. Jorgenson, South Dakota; and J. R. Harbison, Kentucky.

REFERENCE

1. Rudy, B.M., "Operational Route Analysis." HRB Bull. 341, 1-17 (1962).

An Economic Replacement Model for Highway Surface Determination

JOHN W. WORK, JR., Economist, Minnesota Department of Highways

This paper attempts to point out basic inadequacies in the conventional cost approach to highway surface-type determination, and subsequently, presents an economic replacement model couched within a highway framework. The conventional method relies heavily on a static concept of cost, whereas the proposed replacement model recognizes the value of funds over time; the first-mentioned approach requires a predetermined estimate of surface life, whereas the latter method is equipped to make an objective determination of surface life; the replacement approach, in an attempt to recognize all costs associated with the surface structure over its life, includes an estimate of road user cost not present in the HRB method.

Specifically, the model provides a surface replacement solution in terms of an optimum economic time span for pavement type (i.e., rigid or flexible) based on the minimization of an average cost stream over time, where the cost stream is made up of the initial surface structure cost and the anticipated stream of maintenance and road user costs. In this paper the anticipated stream of maintenance costs is simple regression estimates of these costs over the life of selected rigid and flexible pavement structures. The final solutions yielded by the model, in terms of present worth calculations, indicate the comparative total amounts of money needed today to build, maintain, and operate either a flexible- or rigid-type surface structure over time.

• OFTEN in the economic determination of highway surface structures (i.e., rigid or flexible type), a comparison of alternative costs by the Highway Research Board's annual cost formulation is used[1]. Given highway location and design, highway officials must decide on "surface type," and such a decision should be couched in such terms as initial cost, estimated surface life, estimated future maintenance costs, and traffic volumes. This paper contends that the basis of most present methods of computing surface structure costs precludes proper consideration of these factors. On the other hand, is there a method of estimating highway costs which can account properly for the previously mentioned variables?

The basic aim of this paper, therefore, is briefly to discuss basic aspects of the HRB method of estimating highway costs in particular and subsequently present an economic model that attempts to recast factors crucial in highway decision making in a somewhat different framework.

HIGHWAY RESEARCH BOARD METHOD

The abbreviated HRB formula for computing annual road costs as presented by Breed (5, p. 94) is

Paper sponsored by Committee on Highway Costs.

[1] Actually the HRB annual cost formulation has been reformulated as an approximation by Breed (5).

$$C = \left(\frac{A+S}{2}\right) r + \left(\frac{A-S}{n}\right) + B + \frac{E}{n} \quad (1)$$

in which

C = average annual cost;
A = original capital cost;
B = annual maintenance cost;
r = rate of interest;
n = estimated life of surface;
S = estimated salvage value of highway at end of n years; and
E = required periodic maintenance during n.

The first term of the equation computes an average annual interest payment; the second term provides for straight-line depreciation; a combination of these terms yields a simple average annual capital cost figure (12, p. 491). The results are more valuable from a cost-accounting standpoint rather than an economic one, i.e., cost accounting in the sense that the model assumes the initial cost to be borrowed and repaid in amounts equal to annual average depreciation plus interest (6, pp. 177-178). The third and fourth terms describe the entire maintenance pattern as averages added to the average depreciation and interest figures for an estimate of total average annual cost. An average annual cost so derived for a particular type of surface structure is then compared with a similarly found value for a second type of surface structure. That type exhibiting minimum average annual cost is considered the optimum.

The following are the basic objections to this approach for highway surface structure costs:

1. The HRB method does not distinguish between value and cost. That is, the method in question defines a static pattern of cost allocation (which is useful to the cost accountant) rather than a pattern of changes in the usefulness or utility associated with a given facility (18, Chs. 8 and 9).
2. As a result of "averaging," the HRB formulation does not account for the intertemporal value of money over n.
3. The expected life (n) of a facility in no way reflects the period of economic or physical replacement.
4. The HRB formulation does not take into account the element of road user cost. If n is assumed to be some function of overall costs, then road user costs must be given consideration in addition to initial and maintenance costs, because the value of the highway (value expressed in terms of economic utility) would remain constant if, for some reason, no vehicles were allowed to use the facility. (The assumption is that in the short-run, technological innovations, various forms of obsolescence, climatic vagaries, and the like, are constant. Therefore, any changes in the value of the highway are necessarily engendered by road users. By the same token, any maintenance expenditures would exist only as a function of traffic volumes, and in the absence of such volumes would presumably be nil.)

ALTERNATE APPROACH

Important Considerations

In private industry, the introduction of new technology, cheaper sources of raw material, etc., enable an entrepreneur to compete more efficiently through price adjustment. These efficiency factors imply a lower unit cost structure facing an entrepreneur, which in turn implies a lower unit price structure facing consumers. The lowered price structure further implies that consumers are maximizing their expenditures. (This statement implies, from an economics standpoint, that the value of the monetary unit remains constant.) Highway surface determination, a concern of government, must rest on the total cost of a given surface structure over the life of that structure. Moreover, that surface is preferable whose entire structure has the lowest overall initial, maintenance, and road user costs. Stated differently, the goal should be the selection of that surface type possessing economic advantage. As in the case of private industry, the advantages stemming from a relatively low set of costs make sense only insofar as the public is now able to consume (or use) a given highway at some optimally minimum price.

Because the cost of building, maintaining, and operating highways is covered by road user taxes[2], the government becomes obligated, in an economic sense, to build roads that can be consumed at some relatively minimum price. This is true because the price paid by road users (which they view as the cost of vehicle operation, maintenance, time, etc.) will be a function of the initial road cost, maintenance cost, and anticipated surface life. Thus, in the proposed model, an estimate of road user costs is included.

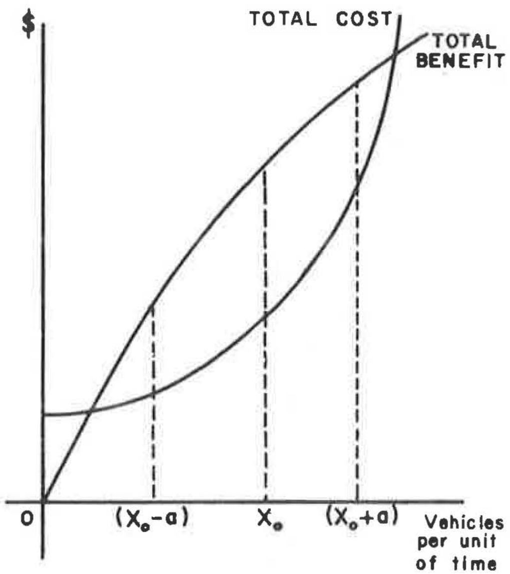

Figure 1. Total cost and benefit curves.

Model

The proposed model involves essentially the computing of the present worth of present and future highway construction, maintenance, and road user costs. In addition, the process indicates an optimal economic time for surface replacement as a function of minimum weighted average discounted costs. This "economic surface replacement time" is not necessarily the same as the actual physical replacement often dictated by engineering experience and consideration. To this extent it is basically an economic replacement model.

The economic significance of "minimum weighted average discounted cost" deserves some theoretical attention because it occupies a place of basic importance in the model. Figure 1 shows the hypothetical long-run path of total cost and total benefit associated with increasing numbers of vehicles per unit of time, using a given highway improvement. It is assumed that total cost is made up of initial, maintenance, and road user costs; total benefit may be viewed as a monetary expression of total savings resulting from an improvement in the highway system. Given these two functions, an optimum number of vehicles per unit of time may be found at the point where the difference between total cost and total benefit is maximum. In Figure 1 such a point might be X_0; that is, X_0 vehicles per unit of time derive maximum net benefit from a given highway improvement.

If it is assumed that the number of vehicles using this given improvement increases at some known rate, then it is possible to state that maximum net benefit will accrue, for example, in the 10th year. Moreover, it is demonstrable that for more than X_0 vehicles per unit of time, say $(X_0 + a)$ vehicles, total cost is rising at a faster rate than total benefits. By the same token, total benefits would be rising at a faster rate than total cost at $(X_0 - a)$ vehicles; thus, the justification for using X_0 as the point of optimality.

This reasoning may be enhanced through the use of the average and marginal curves shown in Figure 2. These four curves are derived from the total curves in Figure 1. The optimum number of vehicles, X_0, is found at the point where the marginal cost and marginal benefit curves intersect in Figure 2. These marginal curves are the derivatives of the total curves in Figure 1, and measure the cost and benefit associated with

[2]In general, this is true whether the cost of highways is financed directly from the general fund, or financed by bond issues which, at some point in time, are paid off through taxation. This is not to imply, however, that the economic consequences are identical regardless of the method of financing.

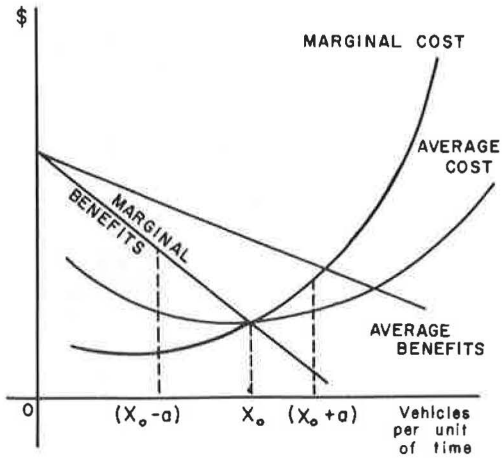

Figure 2. Average and marginal cost curves.

an additional or marginal unit; i.e., $(X_0+a) - X_0$. The marginal unit at $(X_0 - a)$ vehicles in Figure 2 will receive benefits in excess of costs as measured by the vertical distance between the marginal cost and marginal benefit curves. Hence, it would pay more units to use the improvement; i.e., up to the point where the cost to the last unit of vehicles is just offset by benefits. If the number of vehicles increases beyond X_0, then the cost to the marginal unit exceeds benefits; thus, vehicle expansion is economically unfeasible. Moreover, in terms of Figure 1, the addition of vehicle units beyond X_0 would produce a decline in total net benefit. The proposed model, therefore, suggests surface replacement in a time period correspondent to X_0 vehicles.

The marginal cost curve bisects the average cost curve at the minimum point of the latter. The nature of their relationship to the total cost curve precludes a bisection of the average cost curve by the marginal cost curve at any point other than the minimum. However, that the marginal benefit curve cuts the average cost curve at its minimum point, occurs here by assumption. This critical assumption is that officials responsible for the highway improvement have correctly estimated benefits accruing over time in terms of the improvement, maintenance, and road user costs. For if they were to overestimate or underestimate the pattern of benefits, the average and marginal benefit curves would fall to the left and right, respectively, of the minimum point on the average cost curve. This paper is not concerned with these consequences, however, because the proposed replacement model always assumes that the optimum point is determined at average cost = marginal cost = marginal benefit.

Such a replacement approach has several advantages (1) over the conventional HRB method:

1. The proposed method stresses economic optimization rather than conventional financial considerations.
2. Separate forecasting of maintenance and road user costs is necessary, and these forecasts will automatically include estimates of technological innovation and obsolescence.
3. The selection of an economic surface replacement date by the proposed method is objectively determined as a function of all costs.
4. It is possible to ascertain the nature of an optimal pattern of maintenance costs once the other variables are known, and also optimal traffic volumes given the other variables.

The following are the general assumptions used:

1. Costs of rough-grading, right-of-way, landscaping, and structures are identical for both flexible and rigid surface structures, and therefore, may be omitted from the comparison.
2. All costs (i.e., capital, maintenance, and road user) are paid at the time in which they are incurred. Moreover, the present worth structure tells how much money would be needed today to meet both present and future costs. Thus, future annual highway costs paid at the time in which they are incurred are composed of maintenance and incremental road user costs only. Incremental road user cost is the additional cost resulting from an increase in traffic volumes. Normally, it would be reasonable to recognize that over time, unit vehicle-operating costs would tend to rise. However, for purposes of demonstrating this model, it is sufficient to assume that unit vehicle-operating costs remain constant. A further assumption is that a rising annual maintenance

cost curve implies restoration of the roadway to its initial state after each year. There fore, incremental road user cost will be considered a function of the sum of increments in traffic volumes, and may be stated as $(C_2' - C_1')$, $(C_3' - C_1')$, ..., $(C_n' - C_1')$ in which C_i' is total road user cost in time period i.

3. At the time of replacement, only resurfacing costs (rather than surface structure costs) need be considered because the lives of other items that constitute a surface structure are assumed to be infinite. (In this assumption, the problem of salvage value is brought under control because only resurfacing costs are equated to replacement costs, and the time span is considered infinite. On the other hand, some estimate of salvage value may be accounted for by adjusting the cost of resurfacing.)

4. The rate of interest used to discount future costs is 7 percent (Appendix). The selection of an appropriate rate of interest for economy studies is presented elsewhere (11, 14, 26).

Having stated the basic assumptions underlying the proposed replacement model, it is assumed further that, in constructing some typical mile of highway, the alternatives are (a) rigid surface structure, or (b) flexible surface structure. If A is the initial or first cost of either type of surface structure; A' is the cost of resurfacing the structure when necessary; C_i is the projected annual maintenance cost and road user cost differences in the ith year; the factor $1/(1 + r)^{i-1}$ computes the present worth of future costs when given the rate of interest r; then,

$$K_n = A + C_1 + \frac{C_2}{1+r} + \frac{C_3}{(1+r)^2} + \ldots + \frac{C_n}{(1+r)^{n-1}} + \frac{A' + C_1}{(1+r)^n} + \frac{C_2}{(1+r)^{n+1}} + \ldots + \frac{C_n}{(1+r)^{2n-1}} \qquad (2)$$

This equation describes the complete stream of present and future costs when the highway is to be resurfaced every nth year and where K_n is the total present worth of that stream. When this formulation is applied to both rigid and flexible surface structure costs, the economically optimal facility is that whose total discounted costs (i.e., present worth) are a minimum, and may be selected by direct comparison. The mechanics of this model have been adopted from Churchman, Ackoff, and Arnoff (7); further discussion of replacement models is presented by Alchian (1), Bellman (4), Grant and Ireson (12), and Dean (10).

It is methodologically incorrect to compare total costs, based on a single life cycle, of two surface structures whose lives are estimated to be different. Consequently, it becomes necessary to establish cyclical iterations so that ultimately only an equal number of time periods are compared; i. e., finding the least common multiple. In actual applications to highway surface determination problems, however, the number of iterations can be high so that the entire valuation process, based on present worth factors, often tends toward infinity (general assumption 3). Now if this assumption of infinity is made (i.e., where the discount factors are a convergent series over time), then,

$$K_n = A + \frac{A' + \sum_{i=1}^{n} \left[\frac{C_i}{(1+r)^{i-1}} \right]}{1 - \left[\frac{1}{(1+r)^n} \right]} \qquad (3)$$

This equation shows how much money will be needed today initially to construct the road and resurface it every nth year. For economy studies, this approach is quite acceptable; on the other hand, from an accounting or financing standpoint, such a formulation would be meaningless.

(Actually, Eq. 3 results in a duplication of initial surface cost because this cost is implicit in A and explicit in A′. Perhaps more correctly, the equation should be

$$K_n = (A - A') + \frac{A' + \sum_{i=1}^{n} \left[\frac{C_i}{(1+r)^{i-1}} \right]}{1 - \left[\frac{1}{(1+r)^n} \right]} \tag{4}$$

This is because it is assumed that only the surface (wearing course) is replaced every n years. But this would not apply to rigid structures unless it is assumed that such a structure is resurfaced with concrete rather than asphalt. Throughout this study, however, it is assumed that K_n, as expressed in Eq. 3, is a good approximation of costs.)

The computation of K_n assumes that n is objectively determined. If, for a given surface structure type, K_n is a minimum, then it can be demonstrated that $K_{n+1} - K > 0$ and $K_{n-1} - K > 0$. These cost-minimizing inequalities may be verbalized in terms of weighted average costs where the sum of the discount factors are used as weights. Thus, one should resurface every n years if the weighted average of all previous costs in the nth year is less than the actual undiscounted cost in the nth + 1 year. In other words,

$$C_{n+1} > \frac{A + C_1 + \frac{C_2}{1+r} + \frac{C_3}{(1+r)^2} + \ldots + \frac{C_n}{(1+r)^{n-1}}}{1 + \frac{1}{1+r} + \frac{1}{(1+r)^2} + \ldots + \frac{1}{(1+r)^{n-1}}}$$

A complete mathematical analysis of these cost-minimizing rules is given by Churchman, et al. (7, pp. 485-7).

APPLICATION OF MODEL TO ACTUAL DATA

In testing the model as presented in the foregoing section, it was necessary to procure three types of data: (a) highway maintenance cost data, (b) projected road user cost, and (c) initial or first cost per mile. These data were obtained from Minnesota Highway Department records and traffic engineering forecasts. This section describes the treatment of the data, its inclusion in the model, and the results of the analysis.

Maintenance Cost Patterns

The proposed replacement model requires that a projected pattern of total surface maintenance costs be estimated over the life of a given surface type. In meeting this requirement, sample control sections of rigid and flexible highways were obtained from the total highway mileage in the State of Minnesota. In drawing a sample of control sections, three governing factors were present because the basic concern was the establishment of cost patterns over the surface life of a facility. First, only those control sections exhibiting a completed surface life (i.e., from time of initial construction to time of complete resurfacing) were considered. Secondly, though the flexible roads were predominantly low-type structures, it was decided on statistical grounds not to mix whatever scant information available on high-type flexible surfaces with that on low-type surfaces. Thirdly, all maintenance cost figures apply to one roadway. (Maintenance cost records are only available since 1939; therefore, all cost observations are contained in the 21-year span between 1939-60.)

Highway maintenance expenditures were divided into routine maintenance and special maintenance. Routine maintenance may be defined as the regular and normal maintenance to prevent and correct minor deterioration of the surface structure. Special maintenance is distinguished from routine maintenance in that the former is periodic and includes major restoration of a surface structure, and/or repair of structural failure. Normally, special maintenance also includes resurfacing; however, these costs have been deleted, insofar as possible, from the sample.

Figure 3 shows the pattern of routine maintenance costs for rigid surface structures. The parabolic regression curve is based on an averaging of per mile year-to-year costs over the life of 14 control sections. Moreover, these and other costs have been converted into constant dollars; i. e., the 1947-49 general price index = 100 was used to deflate the actual money costs, so that changes in the value of money would not appreciably affect the averaging process. Figure 4 is a summary of special maintenance costs for rigid surface structures. Because of the unexplained variability in these data, the semi-average method for determining trends was used. (The semi-average trend line is easily distorted by extreme values. Hence, Figure 4, at best, is a rough estimate of special maintenance costs.) Figure 5, which is the summation of Figures 3 and 4, is a completed estimate of annual per mile maintenance costs for rigid surface structures. Figures 6, 7, and 8 are similar cost estimates for a sample of 15 flexible surface control sections. Tables 1 and 2 summarize all estimated and extrapolated maintenance costs over a 30-year period.

Projected Annual Road User Costs

As stated earlier, C_i is composed of both annual maintenance and incremental road user costs per mile. It is assumed that incremental road user cost is a function of some linear change in traffic volumes. That is, if, for example, an ADT of 6, 500 is expected in year 1, and 8, 000 ADT is forecast for year 15, then the annual incremental increase in vehicles will approximate 107 vehicles in year 2, 3, . . . , 15. The incremental ADT figures should then be converted into "passenger car equivalent" so as to account for trucks and other commercial vehicles (2, p. 29). Once annual incremental traffic volumes are determined, the computation of annual per mile road user costs is a straightforward process (2, Sec. I)(Tables 3 and 4).

Case 1

A decision was made to redesign and reconstruct approximately 10 miles of highway in the State of Minnesota. The total per mile initial construction cost for a rigid surface structure was estimated at $96, 277; the same cost for a flexible surface structure was estimated at $89, 292. (For purposes of this study, any salvage value contained in the old road is assumed not to exist. In other words the old road is considered as if it were a newly constructed highway.) The present ADT in terms of passenger car equivalent is 2, 310 vehicles; the forecasted 1980 passenger car equivalent is 3, 376 vehicles. These PCE figures translated into annual per mile roaa user costs are given in Table 3. (The constant unit cost shown in this table as well as in Table 4 reflects not only fuel, tires, and oil but also repairs, depreciation, time, and comfort and convenience. There is some question as to whether these latter costs should be included or excluded from the total unit cost for purposes of this study. As can be seen, exclusion of these costs will result in longer surface replacement times than given in Tables 5 through 8.) To these annual road user cost figures are added the estimated annual per mile maintenance cost figures for both rigid and flexible surface structures given in Tables 1 and 2. The model, as applied to these various costs for Case 1, is given in Tables 5 and 6. [The general form for Tables 5 through 8 has been borrowed directly from Churchman, et al. (7, p. 488).] The time of surface (not "surface structure") replacement for both rigid and flexible surfaces as a function of weighted average costs is 11 years. Both tables show that continued use of the existing surface beyond the 11th year violates the cost-minimizing principles discussed earlier.

It it is assumed that all resurfacing, regardless of existing surface structure type, is done with asphalt, and a 2-in. overlay for a single roadway will cost approximately $13, 962 per mile, then the minimum total amount of money needed today to cover all future costs including surface replacement every 11 years for the rigid surface structure is estimated as K_{11} = $96, 277 + ($13, 962 + $63, 859)/(1-0.4751) = $244, 536. A similar calculation for the proposed flexible surface structure would be K_{11} = $89, 292 + ($13, 962 + $66, 506)/(1-0.4751) = $242, 594. A direct comparison of these results indicates that in terms of today's money, the proposed flexible surface structure can be constructed, maintained, and its surface replaced every 11 years, for $1, 942 less than the minimum cost of the proposed rigid surface structure.

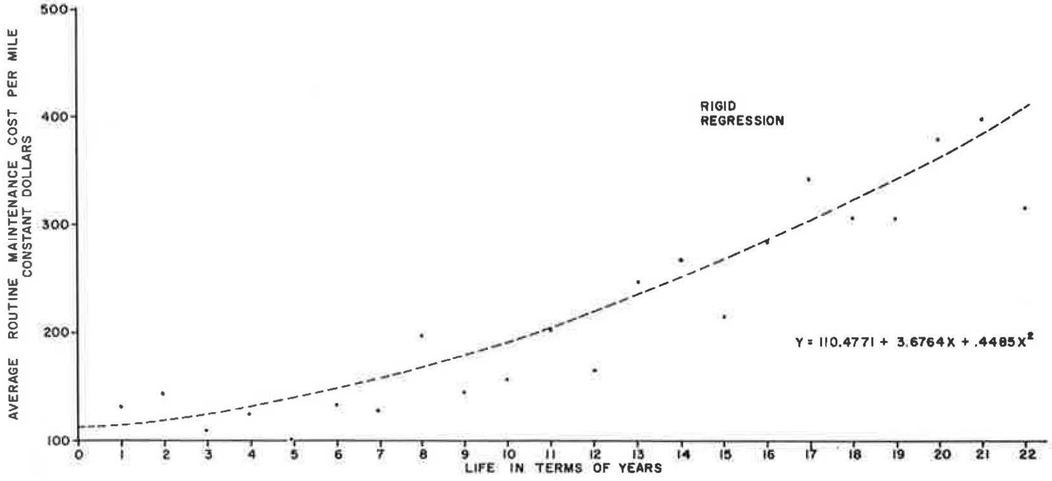

Figure 3. Time series relating routine maintenance costs to rigid surface structure life (one roadway).

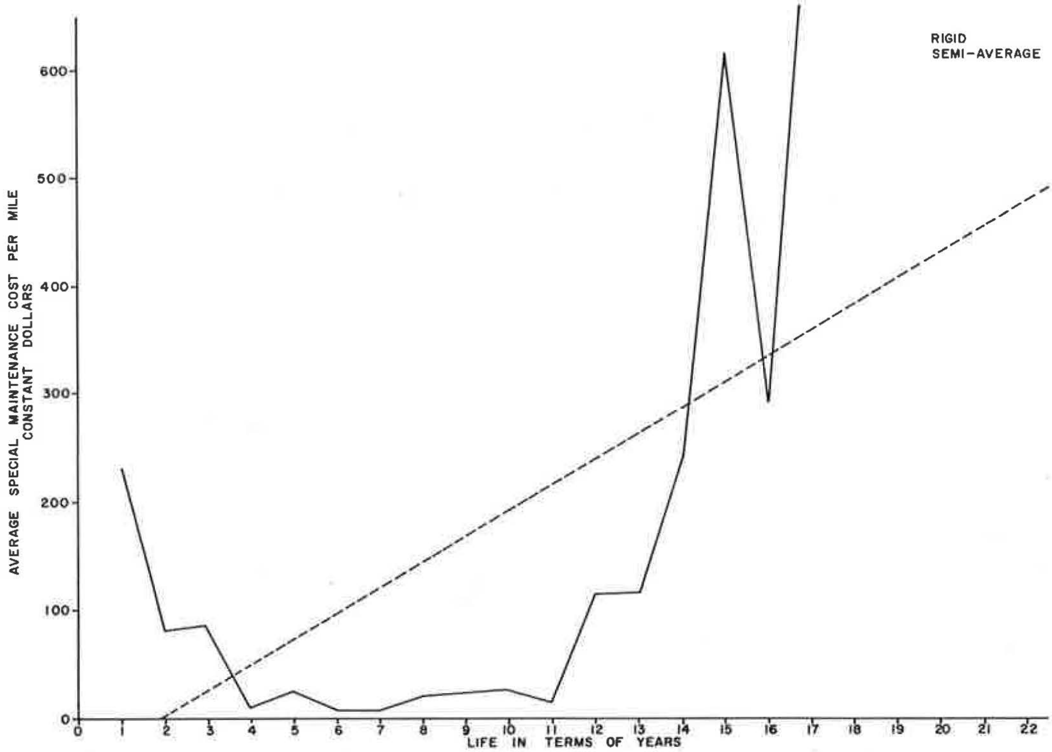

Figure 4. Semi-average trend line describing path of special maintenance costs over rigid surface structure life (one roadway).

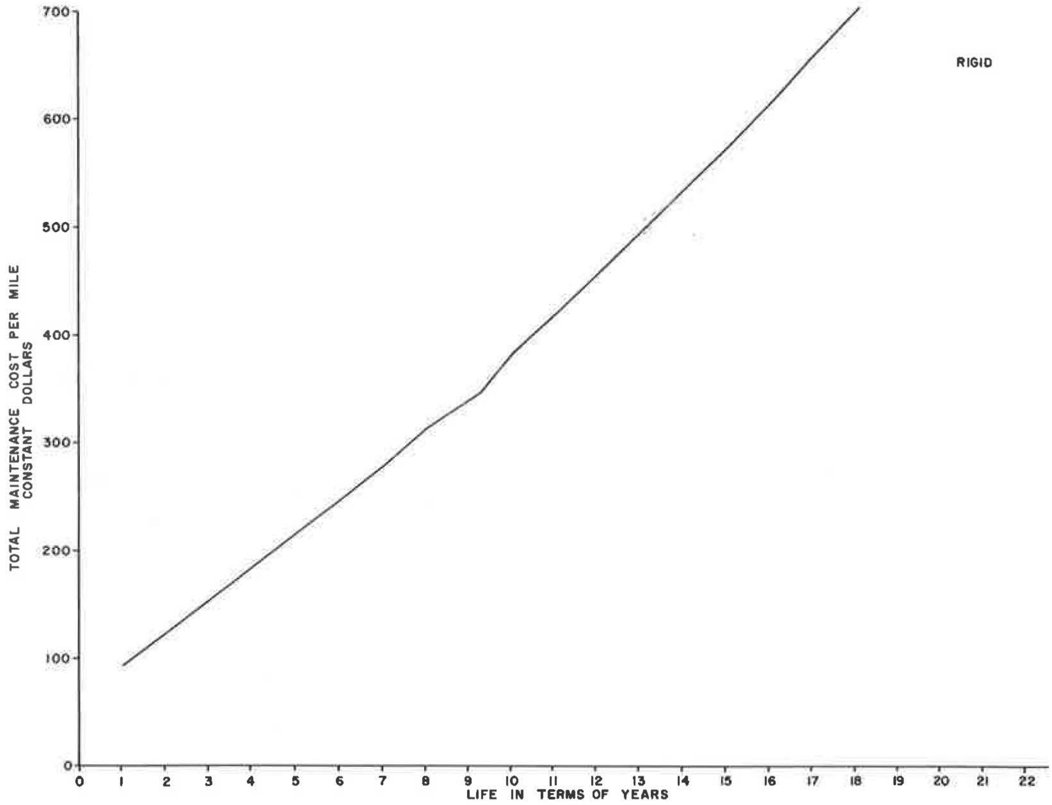

Figure 5. Sum of Figures 2 and 3, showing estimated total average maintenance costs for rigid surface structure life (one roadway).

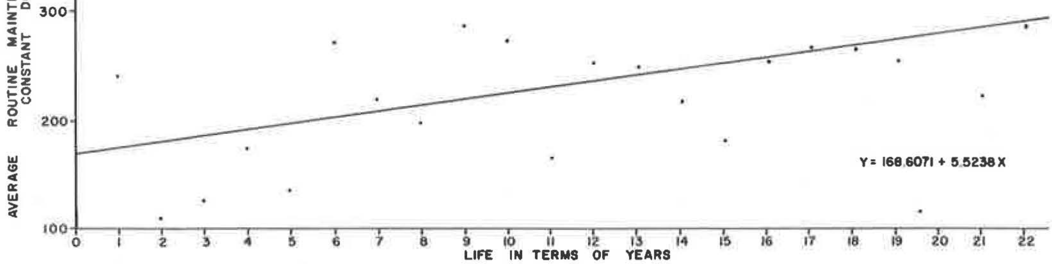

Figure 6. Time series relating routine maintenance cost to flexible surface structure life (one roadway).

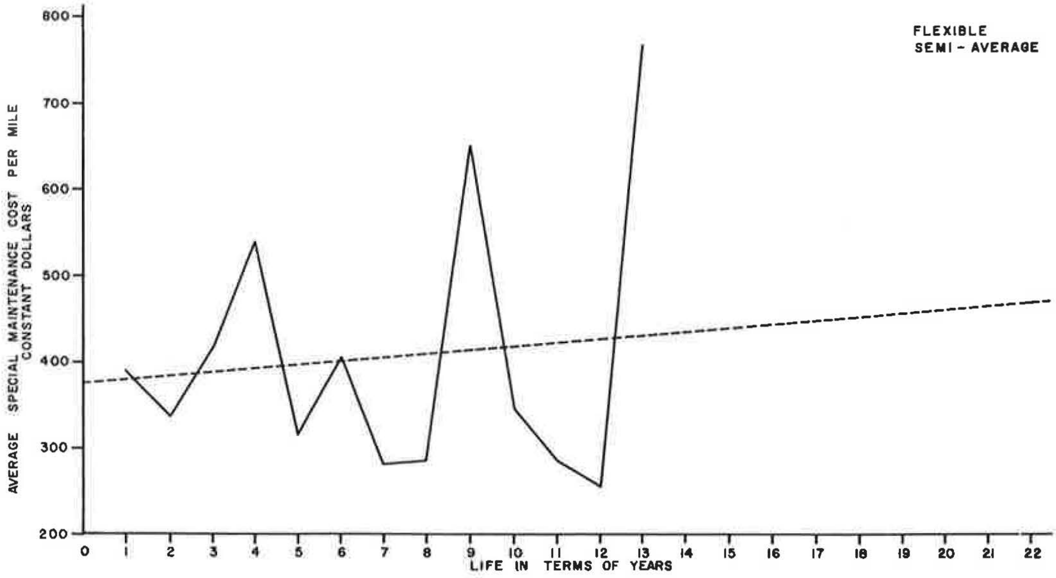

Figure 7. Semi-average trend line describing path of special maintenance costs over flexible surface life (one roadway).

Case 2

Case 2 involves a section of road located in the northern part of Minnesota, and is described in Tables 4, 7, and 8. The same maintenance cost figures and the unit road user costs are assumed to be applicable here as in Case 1. The present PCE on this roadway was estimated to be 1,968 vehicles, and the 1980 PCE forecast estimated 3,412 vehicles. The total initial per mile cost for a rigid surface structure is estimated at $71,254; the total initial per mile cost for a flexible structure is estimated to be $44,285. Tables 7 and 8 show, on the basis of all cost estimates, that the proposed rigid and flexible surfaces should be replaced each 8 and 6 years, respectively. Thus,

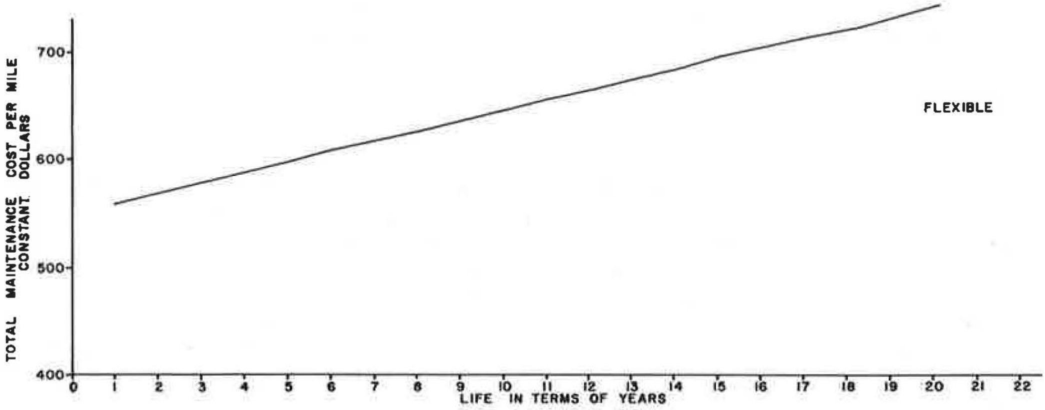

Figure 8. Sum of Figures 6 and 7, showing estimated total average maintenance costs for flexible surface structure life (one roadway).

TABLE 1

TOTAL ESTIMATED PER MILE MAINTENANCE COSTS FOR FLEXIBLE SURFACE STRUCTURES

Year	Estimated Costs (constant dollars)		
	Per Mile Routine Maintenance	Per Mile Special Maintenance	Per Mile Total Maintenance
1	175	379	554
2	180	383	563
3	186	388	574
4	191	392	583
5	197	396	593
6	202	400	602
7	208	404	612
8	213	408	621
9	219	413	632
10	224	417	641
11	230	421	651
12	235	425	660
13	241	429	670
14	246	433	679
15	252	438	690
16	257	442	699
17	263	446	709
18	268	450	718
19	274	454	728
20	280	458	738
21	285	463	748
22	291	467	758
23	296	471	767
24	302	475	777
25	307	479	786
26	313	483	796
27	318	488	806
28	324	492	816
29	329	496	825
30	335	500	835

TABLE 2

TOTAL ESTIMATED PER MILE MAINTENANCE COSTS FOR RIGID SURFACE STRUCTURES

Year	Estimated Costs (constant dollars)		
	Per Mile Routine Maintenance	Per Mile Special Maintenance	Per Mile Total Maintenance
1	116	-21	95
2	120	2	122
3	126	26	152
4	133	49	182
5	140	73	213
6	149	96	245
7	159	120	279
8	169	143	312
9	180	167	347
10	193	190	383
11	205	214	419
12	220	237	457
13	235	261	496
14	251	284	535
15	267	308	575
16	285	332	617
17	304	355	659
18	322	379	701
19	343	402	745
20	364	426	790
21	386	449	835
22	409	473	882
23	433	496	929
24	457	520	977
25	483	543	1,026
26	510	567	1,077
27	537	590	1,127
28	566	614	1,180
29	595	637	1,232
30	625	661	1,286

the total minimum of all present and future costs associated with the rigid structure is K_8 = \$71,254 + (\$13,962 + \$50,149)/(1-0.5820) = \$224,630. The total minimum present and future costs for the proposed flexible structure is K_6 = \$44,285 + (\$13,962 + \$31,095)/(1-0.6663) = \$179,308. A direct comparison of K_8 and K_6 shows that the proposed flexible structure is \$45,322 less than the rigid structure when its replacement cycle is 6 years.

SUMMARY AND CONCLUSIONS

An attempt has been made to present an economic replacement cost model that properly takes into account present and future costs associated with surface structure types, and reveals, on the basis of these costs, some minimally optimal total cost. The presumption, of course, is that some optimal n is determinate. In the cases presented, n appears unrealistically low for replacement in terms of highway experience. However, the surface life dictated by the replacement model is based primarily on economic rather than engineering considerations. Hence, from the standpoint of this study, n signifies a point of minimum cost, and need have no implications for actual surface replacement.

The methods for arriving at various estimates of maintenance and road user costs in this study are by no means definitive, nor are they intended to be. Estimating pro-

TABLE 3

ESTIMATED ANNUAL INCREMENTAL ROAD USER COST[1], CASE 1

Year	PCE	Annual Incremental Road User Cost ($)
1	0	0
2	55	1,795
3	110	3,589
4	165	5,384
5	220	7,179
6	275	8,974
7	330	10,768
8	385	12,563
9	440	14,358
10	495	16,152
11	550	17,947
12	605	19,742
13	660	21,536
14	715	23,331
15	770	25,126
16	825	26,921
17	880	28,715
18	935	30,510
19	990	32,305
20	1,045	34,099
21	1,100	35,894
22	1,155	37,689
23	1,210	39,484
24	1,265	41,278
25	1,320	43,073
26	1,375	44,868
27	1,430	46,662
28	1,485	48,457
29	1,540	50,252
30	1,595	52,046
31	1,650	53,841
32	1,705	55,636
33	1,760	57,431
34	1,815	59,225

[1]For 365 days per year, per one-mile length, at a unit cost of $0.0894.

TABLE 4

ESTIMATED ANNUAL INCREMENTAL ROAD USER COST[1], CASE 2

Year	PCE	Annual Incremental Road User Cost ($)
1	0	0
2	75	2,447
3	150	4,895
4	225	7,342
5	300	9,789
6	375	12,237
7	450	14,684
8	525	17,131
9	600	19,579
10	675	22,026
11	750	24,473
12	825	26,921
13	900	29,368
14	975	31,815
15	1,050	34,263
16	1,125	36,710
17	1,200	39,157
18	1,275	41,605
19	1,350	44,052
20	1,425	46,499
21	1,500	48,947
22	1,575	51,394
23	1,650	53,841
24	1,725	56,288
25	1,800	58,736
26	1,875	61,183
27	1,950	63,630
28	2,025	66,078
29	2,100	68,525
30	2,175	70,972
31	2,250	73,420
32	2,325	75,867
33	2,400	78,314
34	2,475	80,762

[1]For 365 days per year, per one-mile length, at a unit cost of $0.0894.

cedures will vary, no doubt, from analyst to analyst depending on available data, degree of desired sophistication, etc. Moreover, the actual maintenance cost data used in this paper are in some instances incomplete, and therefore, do not lend themselves to a high degree of cost accuracy. One potential point of danger is the inclusion of annual incremental road user costs. This value is extremely sensitive to ADT estimates. It need not, however, seriously affect the outcome of a cost comparison because the same road user costs are part and parcel of the estimates compared. Nonetheless, the more accurate the ADT forecast (?), the more significant road user costs become in the analysis.

Throughout this study, the assumption that maintenance expenditures restore the roadway to its initial state and, therefore, make possible the use of a constant unit road user cost is not wholly satisfactory. What would be more desirable, of course,

TABLE 5

CASE 1, RIGID SURFACE, A = 96,277, r = 7%

No. of Years	C_i	$\frac{1}{(1+r)^{i-1}}$	$C_i\left[\frac{1}{(1+r)^{i-1}}\right]$	$A+\Sigma C_i\left[\frac{1}{(1+r)^{i-1}}\right]$	$\Sigma\left[\frac{1}{(1+r)^{i-1}}\right]$	Weighted Average
	(1)	(2)	(3)	(4)	(5)	(6)
1	0	1.0000	0	96,277	1.0000	96,277
2	1,890	0.9346	1,766	98,043	1.9346	50,679
3	3,711	0.8734	3,241	101,284	2.8080	36,070
4	5,536	0.8163	4,519	105,803	3.6243	29,193
5	7,361	0.7629	5,616	111,419	4.3872	25,396
6	9,187	0.7130	6,550	117,969	5.1002	23,130
7	11,013	0.6663	7,338	125,307	5.7665	21,370
8	12,842	0.6228	7,998	133,305	6.3893	20,864
9	14,670	0.5820	8,538	141,843	6.9713	20,347
10	16,499	0.5439	8,974	150,817	7.5152	20,068
11	18,330	0.5084	9,319	160,136	8.0236	19,958
12	20,161	0.4751	9,579	169,715	8.4987	19,970
13	21,993	0.4440	9,765	179,480	8.9427	20,070
14	23,827	0.4150	9,888	189,368	9.3577	20,237
15	25,661	0.3878	9,951	199,319	9.7455	20,452
16	27,496	0.3625	9,967	209,286	10.1080	20,705
17	29,332	0.3387	9,935	219,221	10.4467	20,985
18	31,169	0.3166	9,868	229,089	10.7633	21,284
19	33,006	0.2959	9,767	238,856	11.0592	21,598
20	34,844	0.2765	9,634	248,490	11.3357	21,921

TABLE 6

CASE 1, FLEXIBLE SURFACE, A = $89,292, r = 7%

No. of Years	C_i	$\frac{1}{(1+r)^{i-1}}$	$C_i\left[\frac{1}{(1+r)^{i-1}}\right]$	$A+\Sigma C_i\left[\frac{1}{(1+r)^{i-1}}\right]$	$\Sigma\left[\frac{1}{(1+r)^{i-1}}\right]$	Weighted Average
	(1)	(2)	(3)	(4)	(5)	(6)
1	0	1.0000	0	89,292	1.0000	89,292
2	2,349	0.9346	2,195	91,487	1.9346	47,290
3	4,152	0.8734	3,626	95,113	2.8080	33,872
4	5,958	0.8163	4,864	99,977	3.6243	27,585
5	7,762	0.7629	5,922	105,899	4.3872	24,138
6	9,567	0.7130	6,821	112,720	5.1002	22,101
7	11,370	0.6663	7,576	120,296	5.7665	20,861
8	13,175	0.6228	8,205	128,501	6.3893	20,112
9	14,979	0.5820	8,718	137,219	6.9713	19,683
10	16,784	0.5439	9,129	146,348	7.5152	19,474
11	18,588	0.5084	9,450	155,798	8.0236	19,417
12	20,393	0.4751	9,689	165,487	8.4987	19,472
13	22,196	0.4440	9,855	175,342	8.9427	19,607
14	24,001	0.4150	9,960	185,302	9.3577	19,802
15	25,805	0.3878	10,007	195,309	9.7455	20,041
16	27,611	0.3625	10,010	205,319	10.1080	20,313
17	29,414	0.3387	9,963	215,282	10.4467	20,608
18	31,219	0.3166	9,884	225,166	10.7633	20,920
19	33,023	0.2959	9,772	234,938	11.0592	21,244

TABLE 7

CASE 2, RIGID SURFACE, A = \$71, 254, r = 7%

No. of Years	C_i	$\frac{1}{(1+r)^{i-1}}$	$C_i\left[\frac{1}{(1+r)^{i-1}}\right]$	$A+\Sigma C_i\left[\frac{1}{(1+r)^{i-1}}\right]$	$\Sigma\left[\frac{1}{(1+r)^{i-1}}\right]$	Weighted Average
	(1)	(2)	(3)	(4)	(5)	(6)
1	0	1.0000	0	71, 254	1.0000	71, 254
2	2, 542	0.9346	2, 376	73, 630	1.9346	38, 060
3	5, 017	0.8734	4, 382	78, 012	2.8080	27, 782
4	7, 494	0.8163	6, 117	84, 129	3.6243	23, 213
5	9, 971	0.7629	7, 607	91, 736	4.3872	20, 910
6	12, 450	0.7130	8, 877	100, 613	5.1002	19, 727
7	14, 929	0.6663	9, 947	110, 560	5.7665	19, 173
8	17, 410	0.6228	10, 843	121, 403	6.3893	19, 001
9	19, 891	0.5820	11, 577	132, 980	6.9713	19, 075
10	22, 373	0.5439	12, 169	145, 149	7.5152	19, 314
11	24, 856	0.5084	12, 637	157, 786	8.0236	19, 665
12	27, 340	0.4751	12, 989	170, 775	8.4987	20, 094
13	29, 825	0.4440	13, 242	184, 017	8.9427	20, 577
14	32, 311	0.4150	13, 409	197, 426	9.3577	21, 098
15	34, 798	0.3878	13, 495	210, 921	9.7455	21, 643

TABLE 8

CASE 2, FLEXIBLE SURFACE, A = \$44, 285, r = 7%

No. of Years	C_i	$\frac{1}{(1+r)^{i-1}}$	$C_i\left[\frac{1}{(1+r)^{i-1}}\right]$	$A+\Sigma C_i\left[\frac{1}{(1+r)^{i-1}}\right]$	$\Sigma\left[\frac{1}{(1+r)^{i-1}}\right]$	Weighted Average
	(1)	(2)	(3)	(4)	(5)	(6)
1	0	1.0000	0	44, 285	1.0000	44, 285
2	3, 001	0.9346	2, 805	47, 090	1.9346	24, 341
3	5, 458	0.8734	4, 767	51, 857	2.8080	18, 468
4	7, 916	0.8163	6, 462	58, 319	3.6243	16, 091
5	10, 372	0.7629	7, 913	66, 232	4.3872	15, 097
6	12, 830	0.7130	9, 148	75, 380	5.1002	14, 780
7	15, 286	0.6663	10, 185	85, 565	5.7665	14, 838
8	17, 743	0.6228	11, 050	96, 615	6.3893	15, 121
9	20, 200	0.5820	11, 756	108, 371	6.9713	15, 545
10	22, 658	0.5439	12, 234	120, 695	7.5152	16, 060
11	25, 114	0.5084	13, 768	133, 463	8.0236	16, 634
12	27, 572	0.4751	13, 099	146, 562	8.4987	17, 245

is an objective measure of the change in the unit cost as a function of maintenance expenditures; i.e., as a roadway deteriorates, presumably unit road user cost will rise. Moreover, one might expect changes in vehicle speed to significantly affect unit road user cost. Unfortunately, such information is not readily obtainable.

In the final analysis, the basic intent of this paper has been to describe an additional method for surface-type determination, and, at the same time, emphasize the advantages of an economic replacement approach relative to conventional financing methods. Though the presentation of the proposed model has purposely avoided the inclusion of much detail, it is hoped that this principle of methodology has aided rather than hindered this effort.

ACKNOWLEDGMENTS

The author is indebted to Deane M. Wenger and Donald D. Carroll of the Minnesota Department of Highways for positive advice and helpful guidance throughout the preparation of this paper. Needless to say, he accepts full responsibility for errors. This study has been made possible by the Minnesota Department of Highways in cooperation with the Bureau of Public Roads but does not necessarily reflect the views of either organization.

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Appendix

The responsibility of government, when confronted with highway alternatives, is to choose an alternate that yields for its constituency the greatest possible return per dollar of expenditure. This makes sense because funds expended for a given highway alternate are no longer available for alternatives. Moreover, such an expenditure in the public sector precludes an equivalent expenditure in the private sector.

It is suggested that only from the standpoint of financing highway projects should the concern with a bond rate, or some other rate on borrowed funds, be paramount; on the other hand, when cast in a strict economic framework, the predominant considerations given to highway projects, as well as to private projects, should be couched in terms of opportunity costs. This is to state that the important costs for an economic comparison of two or more highway projects, or a comparison of public with private projects, are those revealed when the projects are allowed to compete with each other for funds. These opportunity costs may be defined as foregone returns from employing factors of production for a given project rather than some alternate project. Thus, when considering alternative resource-using activities, and when guided by the opportunity cost principle, a pattern of optimal resource allocation within and between the public and private sectors may be established.

This principle can best be illustrated by assuming the existence of a firm whose investment expenditure program lists five independent projects. Further, the project costs and prospective rates of return on each project are those given in Table 9 to their prospective rates of return, and the various combinations of these prospective rates of return, and the various combinations of these projects to their combined rates. In addition, Figure 9 shows the firm's supply of available investment funds (S). This hypothetical supply curve describes the willingness of the firm to invest different sums of money at various rates of return. It is clear, then, that the firm is unwilling to invest any sum of money at less than a 1 percent rate of return; the firm is willing to invest $600 for at least a 4 percent rate of return, $1,800 for a 24 percent minimum rate of return; etc.

The positive slope of the S-curve is engendered by the firm's inability to take advantage of tomorrow's investment opportunities when funds are expended today; i.e., the firm, in some sense, foregoes tomorrow's return in favor of today's gain. Thus, if the firm has only $2,000 for investment purposes, its willingness to commit this sum in total today is tempered by the realization that any potential returns from tomorrow's investment opportunities are necessarily foregone. Hence, the firm, before it will consider such an expenditure, must be assured of a minimum rate of return in the neighborhood of 30 percent (Fig. 9).

TABLE 9

ALTERNATIVE INVESTMENT PROJECTS AND PROSPECTIVE RATES OF RETURN

Project	Total Cost ($)	Rate of Return (%)	Actual Return ($)
1	200	12	24
2	300	8	24
3	400	2	8
4	500	7	35
5	600	16	96

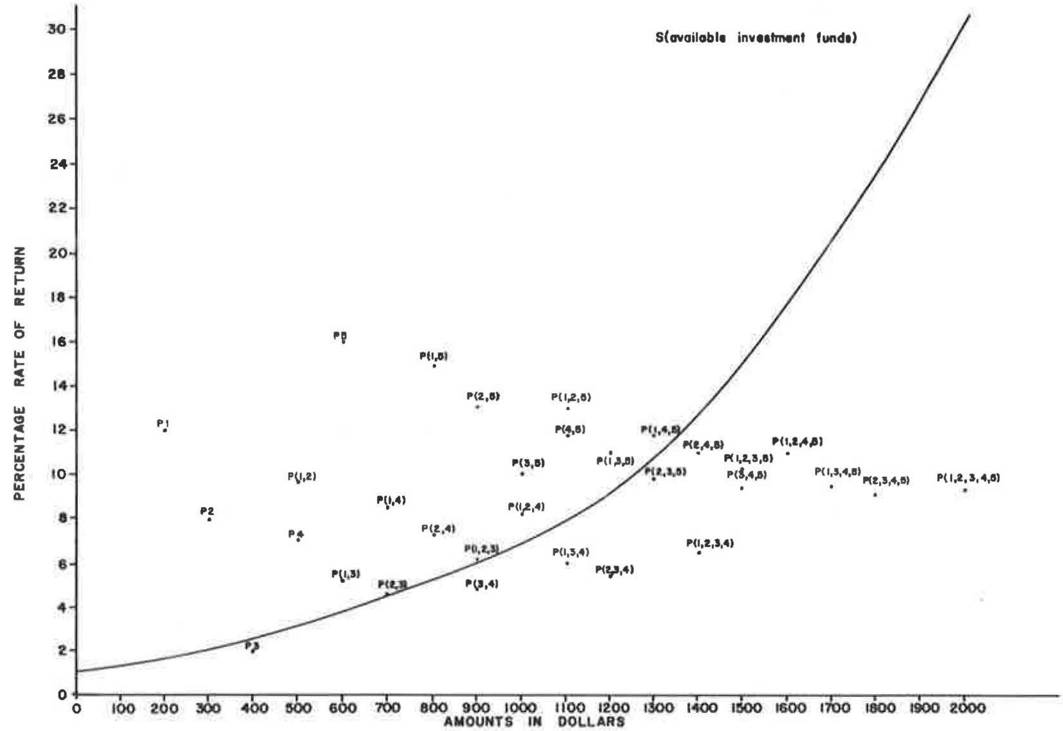

Figure 9. Prospective rates of return on combinations of five projects, relative to supply of available investment funds.

The S-curve, therefore, is a reflection of opportunity cost and economic uncertainty.

Figure 9 is designed to indicate the minimum rate of return the firm is willing to accept from a given project or combination of projects in terms of its opportunity cost picture. There are two separate methods for finding an acceptable minimum rate of return from Figure 9:

1. It is assumed that no limitations on available investment funds exist, and only like combinations are considered; e. g., p(1, 2), p(1, 4), . . . , are compared but not p(1, 3, 4) to p(1, 2);

2. It is assumed that limitations on available investment funds exist, and all projects and their combinations whose total cost equals the available investment funds are considered.

Examining Figure 9 in terms of the first method, and considering projects 1, 2, 3, 4, and 5 individually, the firm will consider the 2 percent yield on p 3 to be the accepted minimum rate if it decides to invest in all five projects. But unfortunately, the prospective rate of return on p 3 is below that rate which the firm must have if it is to invest $400 as shown by the S-curve. Hence, it may be concluded that the firm will consider individually p 1, p 2, p 4, and p 5, and the minimum rate of return acceptable to the firm is the 7 percent yielded by p 4.

Again, if the firm is considering the five projects but interested only in combinations of any three projects, Figure 9 shows ten such possible combinations and their prospective rates of return. Because their combined rates of return do not at least equal the rates at which the firm is willing to invest various sums of money, five of the possible ten combinations are immediately eliminated from consideration. Of those remaining, p(1, 2, 3) yields the lowest rate of return (6.2%) that the firm is willing to accept.

Employing the second method (2), where the assumed restriction is one of limited funds, it is assumed that the firm's investment budget will allow only an expenditure of $1,100. There are three possible combinations which demand this entire sum; namely, p(1, 2, 5), p(4, 5), and p(1, 3, 4). Given the S-curve, it is obvious that the combination p(1, 3, 4) will be dropped from consideration. Of the two eligible combinations, p(4, 5) points to 11.9 percent as the minimum rate of return acceptable to the firm.

The establishment of an acceptable minimum rate of return is as necessary and basic in highway economy studies as in other economy studies, whether private or public. The use of a low discount rate for economy studies makes possible the justification of projects whose rates of return fall below the S-curve. Of course, if it can be successfully argued that the prospective minimum attractive rate of return on taxpayer dollars is low (i.e., 0-3%), then a low rate would be appropriate in highway economy studies. However, empirical evidence has been presented by writers mentioned in the text which suggests an appropriate rate of return of about 5 to 8 percent for such studies.

Discussion

HAROLD W. HANSEN, Senior Planning Engineer, Portland Cement Association, Chicago, Illinois — In capsule form, the author's procedure accepts estimates of current spending for highway purposes with confidence but, because of the vagaries connected with estimating future spending, discounts these by means of price deflators in the form of "present worth factors." (These factors permit calculating the amount of money that must be set aside today at interest which is compounded annually to produce the amount of money estimated to be required in some future year.) After discounting, cost data are accumulated in consecutive years and divided by present worth factors accumulated for the same years. The difference in rate of change of these two parts of the equation results in values which may be plotted to produce a curve that starts at a high value during the early years of the analysis period, declines to some minimal value, and then tends to rise again. The age at which cost has a minimal value is regarded by the author as the "economic life."

The elements of estimated cost used by the author include (a) pavement construction cost, (b) routine and periodic pavement maintenance expense, (c) future resurfacing costs, and (d) the motor-vehicle user "costs" for those vehicles estimated to be added to the traffic stream during the analysis period.

In the example given, the author uses $0.0894 as the unit cost of motor-vehicle operation. This is made up of the elements given in Table 10.

Inclusion of motor-vehicle operating costs constitutes the bulk of the computed "costs" in the author's example and contributes importantly to the short "economic life" which results. Yet the "economic life" computed by the author's model has no demonstrated relationship to the known physical life of pavements in Minnesota.

TABLE 10

UNIT COST OF MOTOR-VEHICLE OPERATION

Element	Estimated Cost ($/veh-mi)
Fuel	0.0211
Tires	0.0040
Oil	0.0021
Maintenance and repairs	0.0120
Depreciation	0.0150
Time	0.0352
Total	0.0894

Principles

The author's four assumptions are derived from concepts by Churchman, et al. (7, pt. 7), whose discussion is primarily on replacement models, which they begin by describing "relevant costs" in replacement theory considerations: "In the problem of choosing between two machines... costs that are the same for the two machines can be excluded in the comparison." When this principle is applied to highways it must be interpreted to mean that road user costs can be excluded except where

TABLE 11

COST COMPUTATION USING MINNESOTA ECONOMIC REPLACEMENT MODEL WHERE THERE IS NO INCREASE IN TRAFFIC IN FUTURE YEARS[1]

Year	Estimated Maintenance Expenditure Trend ($ per mi)	Present Worth Factor (at 7% interest)	Deflated Maintenance Expenditure ($ per mi)	Accumulated Total Maint. and Capital Cost ($)	Accumulated Present Worth Factor (at 7% interest)	Col. 5 Divided By Col. 6 ($)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	0	1.0000	0.00	96,277.00	1.0000	96,277.00
2	95	0.9346	88.79	96,365.79	1.9346	49,811.74
3	122	0.8734	106.55	96,472.34	2.8080	34,356.24
4	152	0.8163	124.08	96,596.42	3.6243	26,652.43
5	182	0.7629	138.05	96,735.27	4.3872	22,049.43
6	213	0.7130	151.87	96,887.14	5.1002	18,996.73
7	245	0.6663	163.24	97,050.38	5.7665	16,830.03
8	279	0.6228	175.56	97,225.94	6.3893	15,216.99
9	312	0.5820	181.58	97,407.52	6.9713	13,972.64
10	347	0.5439	188.73	97,596.25	7.5152	12,986.51
11	383	0.5084	194.72	97,790.97	8.0236	12,187.91
12	419	0.4751	199.07	97,990.04	8.4987	11,530.00
13	457	0.4440	202.91	98,192.95	8.9427	10,980.23
14	496	0.4150	205.84	98,398.79	9.3577	10,515.27
15	535	0.3878	207.47	98,606.26	9.7455	10,118.13
16	575	0.3625	208.44	98,814.70	10.1080	9,775.89
17	617	0.3387	208.98	99,023.68	10.4467	9,478.94
18	659	0.3166	208.64	99,232.32	10.7633	9,219.50
19	701	0.2959	207.42	99,439.74	11.0592	8,915.85
20	745	0.2765	205.99	99,645.73	11.3357	8,790.43
21	790	0.2584	204.14	99,849.87	11.5941	8,612.12
22	835	0.2415	201.65	100,051.52	11.8356	8,453.43
23	882	0.2257	199.07	100,250.59	12.0613	8,311.75
24	929	0.2109	195.93	100,446.52	12.2722	8,184.88
25	977	0.1971	192.57	100,639.09	12.4693	8,070.94
26	1,026	0.1842	188.99	100,828.08	12.6535	7,968.39
27	1,077	0.1722	185.46	101,013.54	12.8257	7,875.86
28	1,127	0.1609	181.33	101,194.87	12.9866	7,792.25
29	1,180	0.1504	177.47	101,372.34	13.1370	7,716.55
30	1,232	0.1406	173.22	101,545.56	13.2776	7,647.88
31	1,286	0.1314	168.98	101,714.54	13.4090	7,585.54
32	1,341	0.1228	164.67	101,879.21	13.5318	7,528.87
33	1,397	0.1147	160.24	102,039.45	13.6465	7,477.33
34	1,454	0.1072	155.87	102,195.32	13.7537	7,430.38
35	1,512	0.1002	151.50	102,346.82	13.8539	7,387.58
36	1,571	0.0937	147.20	102,494.02	13.9476	7,348.50
37	1,631	0.0875	142.71	102,636.73	14.0351	7,312.86
38	1,692	0.0818	138.40	102,775.13	14.1169	7,280.29
39	1,754	0.0764	134.00	102,909.13	14.1933	7,250.54
40	1,817	0.0714	129.73	103,038.86	14.2647	7,224.34
41	1,881	0.0668	125.65	103,164.51	14.3315	7,198.44
42	1,946	0.0624	121.43	103,285.94	14.3939	7,175.67
43	2,012	0.0583	117.30	103,403.24	14.4522	7,154.84
44	2,079	0.0545	113.30	103,516.54	14.5067	7,135.77
45	2,147	0.0509	109.28	103,625.82	14.5576	7,118.33
46	2,216	0.0476	105.48	103,731.30	14.6052	7,102.35
47	2,286	0.0445	101.73	103,833.03	14.6497	7,087.72
48	2,357	0.0416	98.05	103,931.08	14.6913	7,074.32
49	2,429	0.0389	94.49	104,025.57	14.3702	7,062.06
50	2,502	0.0363	90.82	104,116.39	14.7665	7,050.85
51	2,576	0.0339	87.33	104,203.72	14.8004	7,040.60
52	2,651	0.0317	84.04	104,287.76	14.8321	7,031.22
53	2,727	0.0296	80.72	104,368.48	14.8617	7,022.64
54	2,804	0.0277	77.67	104,446.15	14.8894	7,014.79
55	2,882	0.0259	74.67	104,520.82	14.9153	7,007.62
56	2,961	0.0242	71.66	104,592.48	14.9395	7,001.06
57	3,041	0.0226	68.73	104,661.21	14.9621	6,995.08
58	3,122	0.0211	65.87	104,727.08	14.9832	6,989.63
59	3,204	0.0198	63.44	104,790.52	15.0030	6,984.63
60	3,287	0.0184	60.48	104,851.00	15.0214	6,980.10

[1] Based on Table 5.

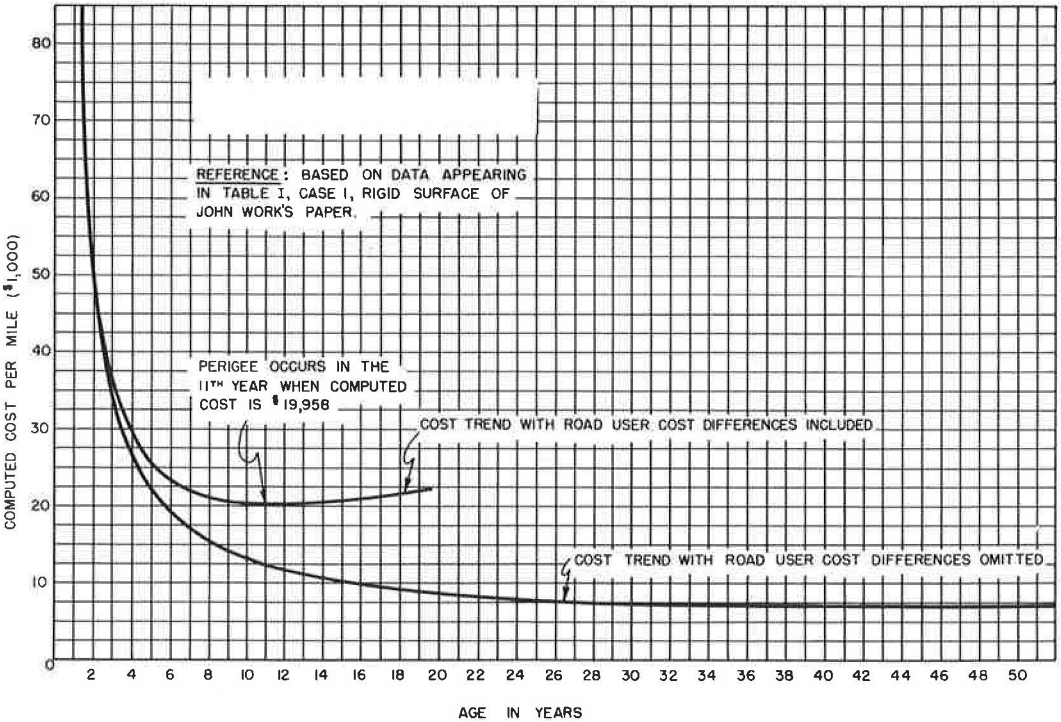

Figure 10. Economic replacement model for highway surface determination (based on Table 5).

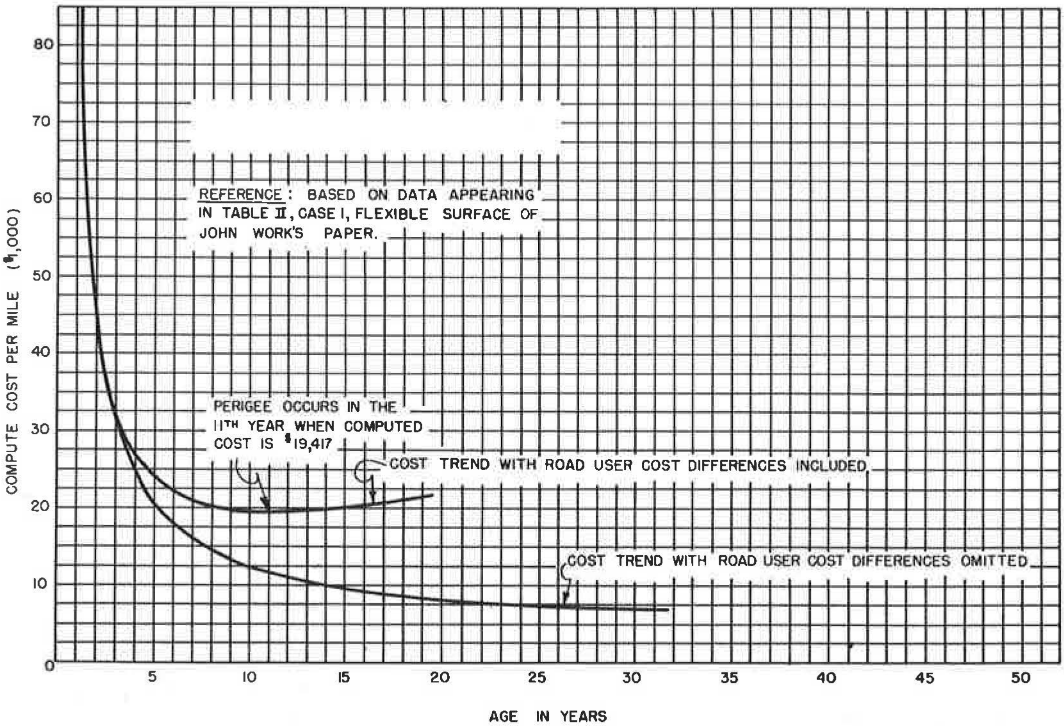

Figure 11. Economic replacement model for highway surface determination (based on Table 6).

TABLE 12

COST COMPUTATION USING MINNESOTA ECONOMIC REPLACEMENT MODEL WHERE THERE IS NO INCREASE IN TRAFFIC VOLUME IN FUTURE YEARS[1]

Year	Estimated Maintenance Expenditure Trend ($ per mi)	Present Worth Factor (at 7% interest)	Deflated Maintenance Expenditure ($ per mi)	Accumulated Total Maint. and Capital Cost ($)	Accumulated Present Worth Factor (at 7% interest)	Col. 5 Divided By Col. 6 ($)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	0	1.0000	0.00	89,292.00	1.0000	89,292.00
2	554	0.9346	517.77	89,809.77	1.9346	46,422.91
3	563	0.8734	491.72	90,301.49	2.8080	32,158.65
4	574	0.8163	468.56	90,770.05	3.6243	25,044.85
5	583	0.7629	444.77	91,214.82	4.3872	20,791.12
6	593	0.7130	422.81	91,637.63	5.1002	17,967.45
7	602	0.6663	401.11	92,038.74	5.7665	15,960.93
8	612	0.6228	381.15	92,419.89	6.3893	14,464.79
9	621	0.5820	361.42	92,781.31	6.9713	13,309.03
10	632	0.5439	343.74	93,125.05	7.5152	12,391.55
11	641	0.5084	325.88	93,450.93	8.0236	11,647.00
12	651	0.4751	309.29	93,760.22	8.4987	11,032.30
13	660	0.4440	293.04	94,053.26	8.9427	10,517.32
14	670	0.4150	278.05	94,331.31	9.3577	10,080.60
15	679	0.3878	263.32	94,594.63	9.7455	9,706.49
16	690	0.3625	250.12	94,844.75	10.1080	9,383.13
17	699	0.3387	236.75	95,081.50	10.4467	9,101.58
18	709	0.3166	224.47	95,305.97	10.7633	8,854.71
19	718	0.2959	212.46	95,518.43	11.0592	8,637.01
20	728	0.2765	201.29	95,719.72	11.3357	8,444.09
21	738	0.2584	190.70	95,910.42	11.5941	8,272.34
22	748	0.2415	180.64	96,091.06	11.8356	8,118.81
23	758	0.2257	171.08	96,262.14	12.0613	7,981.07
24	767	0.2109	161.76	96,423.90	12.2722	7,857.09
25	777	0.1971	153.15	96,577.05	12.4693	7,745.18
26	786	0.1842	144.78	96,721.83	12.6535	7,643.87
27	796	0.1722	137.07	96,858.90	12.8257	7,551.93
28	806	0.1609	129.68	96,988.58	12.9866	7,468.35
29	816	0.1504	122.73	97,111.31	13.1370	7,392.19
30	825	0.1406	116.00	97,227.31	13.2776	7,322.65
31	835	0.1314	109.72	97,337.03	13.4090	7,259.08

[1] Based on Table 6.

a measurable difference in road user costs between alternative pavement types is shown.

For reasons not fully explained, the author included road user costs (although he limited this to the added costs associated with increased traffic volume during future years). In his summary and conclusions, he states: "One potential point of danger is the inclusion of annual incremental road user cost. This value is extremely sensitive to ADT estimates. It need not, however, seriously affect the outcome of a cost comparison because the same road user costs are part and parcel of the estimates compared." By this statement and the data in the report it is clear that the alternatives being compared include equal amounts of road user costs, which by the original premise could have been omitted.

Inclusion of road user cost differences is not only unnecessary but also seriously beclouds some fundamental considerations. This deficiency in the author's approach is particularly significant because road user cost differences represent the preponderance of the costs given in Tables 5 through 9. To illustrate, the value $34, 844 shown in the 20th year in the first column (C_i) in Table 5 is made up of $745 in maintenance costs (Table 2) plus $34, 099 of road user cost differences (Table 3).

Accordingly, maintenance cost is only slightly more than 2 percent of the computed C_i at 20 years. From this point it becomes increasingly more difficult to trace the relationship because of the application of present worth factors to some of the data. Suffice it to say, the $248, 490 given in Col. 4 for the 20th year is comprised of only $96, 277 of initial pavement construction costs. The remaining $152, 213 is made up of about $148, 844 in road user cost and $3, 369 in maintenance cost.

Failure to take into account the fact that maintenance expenditures represent a considerable portion of the overall outlay for highway purposes is being less than realistic. To institute techniques that minimize a major cost is hardly in accord with the principles of sound management. The techniques proposed by the author downgrade maintenance expense to an insignificant role. Accordingly, the method would be insensitive to situations in which maintenance cost on some part of the system is high or exorbitant. Because of this insensitivity, these procedures could not be relied on to determine the more economic alternative where maintenance expenditure is a factor.

In addition to minimizing maintenance costs, the author has introduced into his analysis costs (road user cost differences) that have no real bearing on pavement-type decision making. These costs materially hinder a direct view of the salient factors which should be evaluated in an economic analysis.

Table 11 and Figure 10 show how the data in Table 5 appear with road user cost differences omitted. Although the recomputed table and curve cover a 60-year period, the perigee (point nearest to zero) has not been reached. Furthermore, the curve is so flat that the procedure is decidedly not definitive. Nevertheless, using these data the technique now indicates the economic life is in excess of 60 years. Here again, in the 60th year maintenance costs make up only 0. 05 percent of the computed cost ($104, 851) due to the application of present worth factors as price deflators for maintenance costs.

Table 12 and Figure 11 show similar data for the flexible surface used in Table 6.

Maintenance Expenditures

The "governing factors" outlined in the paper are such that it is difficult to obtain realistic and representative pavement maintenance costs. Restricting the selection to control sections "exhibiting a completed surface life" tends to limit the sample to roads with abnormal problems which were reconstructed earlier than the average of all existing sections. In the case of rigid pavements, which in Minnesota are showing very long service lives, the sample is almost entirely limited to projects constructed before 1930.

Depending on how the analysis is made, the data used by the author could be analyzed to make it appear that per-mile costs decline as age increases.

The author does not indicate that he has taken account of the major factors that influence highway maintenance costs. Without determining the relationship of traffic volume (particularly the frequency and weight of heavier axle loads) to the cost of maintaining State highways, unwarranted generalizations will result.

JOHN W. WORK, Closure — In the main, Mr. Hansen unfortunately misconstrues the intent and fundamental idea of the paper. Therefore, this rejoinder, which forms a basis for clarification rather than debate, comments in turn on the three major points that he makes.

First, Mr. Hansen correctly states that the replacement model determines the economic life of a pavement surface as a function of an average cost stream, a cost stream composed of pavement construction costs, routine and periodic pavement surface maintenance costs, and incremental road user costs. He states further that this economic life bears no "... relationship to the known physical life of pavements in Minnesota." This contention is based on the fact that the lives of rigid and flexible pavements in Minnesota, and throughout the country generally, are thought to be, on the average, approximately 25 years and 18 years, respectively. In the paper, two examples were used to demonstrate the workings of the replacement model when applied to highway surface structures; these examples indicated surface replacement time for specific rigid and flexible surface structures ranging from 6 years to 11 years. Mr. Hansen finds such estimates of surface life vexing— particularly when applied to rigid surfaces. Yet, the paper states very clearly in two places that the concepts of economic surface life and physical surface life are entirely different and that these values need not be expected to correspond.

Physical surface life, as measured by serviceability index, reflects a period (perhaps an average) between initial construction and surface replacement. Obviously, such determination of surface life is based on subjective judgments. Moreover, fluctuations in available highway funds might have an influence on the decision to resurface a roadway at some given point in time. In any event, the important thing to note is that physical life simply tells "what is," rather than "what ought to be," as regards resurfacing. Economic surface life, on the other hand, is independent of judgment in that it is a function of all highway costs. Specifically, economic surface life, as determined by the replacement model, is found at the point of minimum weighted average discounted cost.

Unless one knows what standards dictate road life, hence resurfacing time, the physical or service life average conveys little meaningful information for highway economy studies. Moreover, the nature of physical road life precludes any basic economic consideration.

Figure 12, which is similar to Figure 2, describes what is meant by economic surface life, and what is probably meant by physical or service life. The coordinates are similar to those used in the original paper. The economic life of a surface is found at the point of minimum average cost, where

$$AC = MB = MC \quad (5)$$

in which AC represents average cost, MB represents marginal benefit, and MC represents marginal cost. X_0 vehicles per unit of time is found to be the optimum number of vehicles in terms of initial, road user, and maintenance costs. Additional vehicles will find cost exceeding benefit. This fact notwithstanding, additional vehicles do come onto a facility and continue doing so until vehicle congestion becomes great or the road surface becomes completely worn. Physical surface life, then, is usually an indeterminate point somewhere in the range of X_n vehicles. To put it differently, observable physical life may greatly exceed economic life; but in terms of road user benefits and opportunity costs, which are basic to highway economy studies, the area beyond point X_0 is meaningless.

It is hoped that the foregoing serves to make clear the fact that there certainly is no demonstrable relationship between the economic life and the physical life of road surfaces. It was never intended that the paper should convey anything other than the differences. After all, economic life, as used in the paper, is mathematically determinable as a function of economic costs; physical life, as employed by Mr. Hansen, has no such determinants.

Mr. Hansen's second major criticism revolves around the inclusion of incremental road user cost and "like" road user cost patterns in the determination of an optimum surface struc-

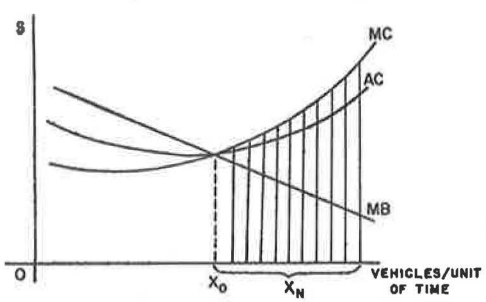

Figure 12.

ture. In support of this criticism, he quotes a passage that leads him to contend that: (a) road user cost differences need not have been included in a comparison of rigid and flexible surfaces because they were assumed to be equal in either case; (b) inclusion of road user cost differences is not only unnecessary but also seriously beclouds some fundamental considerations; (c) road user cost differences are large to the extent of making maintenance cost seem insignificant by comparison; (d) road user cost differences"... have no real bearing on pavement-type decision making."

It appears that this second major criticism and its ramifications rest on a quoted passage not applicable to the surface replacement model. On the contrary, that passage has a specific reference to the problem of choosing between machines (or highways) when the replacement time has already been determined or assumed. In the surface replacement model, the goal is to determine an optimum surface replacement time as a function of all relevant costs; i. e., all costs which vary with the age of the highway surface. The exclusion of road user costs (differences) from the model because they are equal in a comparison of surface types would produce misleading results. This is to say, the replacement time would be stated as a function of only initial and maintenance costs, and as a function of just these costs, replacement time would be ridiculously long, as Mr. Hansen discovered by constructing Tables 11 and 12, and Figures 10 and 11.

The inclusion of a road user cost element tends to complete the "economy study" matrix. In the paper, assumptions and reasons for the inclusion of a road user cost element are stated. Thus, there seems to be no reason for repetition. Suffice it to suggest that Mr. Hansen's reluctance to accept an element of road user cost in the replacement model stems partly from a misunderstanding about the role of equal cost patterns in economy studies, and a concentration upon highway financing rather than upon highway economics. These factors serve to seriously undermine the cogency of this particular criticism.

The third and final major criticism centers its emphasis on maintenance cost as a replacement model factor. The discusser's first contention is that maintenance expenditures make up a significant portion of total highway expenditures, but the replacement model works to make maintenance expenditures appear relatively small. Should he not have expected this result in view of the present worth formulation employed? Each year's maintenance expenditure (surface maintenance only) is converted into present worth terms, the value of which grows at a smaller and smaller rate over time. (The rate at which this occurs, of course, depends on the rate of discount.) This is in contrast to conventional financing procedures, which do not account for the value of money over time; hence, any summation of these unadjusted conventional maintenance values over the physical life of a surface (e.g., 25 years) will constitute a large percentage of total highway cost.

In the replacement model, incremental road user cost is also included as a major cost element. In the two examples presented, incremental road user cost was rising at a much faster rate than the estimated surface maintenance cost. Consequently, maintenance expenditures as a percentage of initial outlay and incremental road user cost appear relatively small. This occurrence gives rise to Mr. Hansen's statement: "Failure to take into account the fact that maintenance expenditures represent a considerable portion of the overall outlay for highway purposes is being less than realistic. To institute techniques that minimize a major cost is hardly in accord with the principles of sound management. The techniques proposed by the author downgrade maintenance expense to an insignificant role."

The fact is that total maintenance expenditures, from an accounting standpoint, do indeed "represent a considerable portion of the overall outlay for highway purposes," when one considers only the costs of building and maintaining a roadway. But initial and surface maintenance expenditures only make sense from an economics standpoint when they are properly related to the cost of using and consuming the roadway. Would Mr. Hansen contend that it is "sound management" to build and/or maintain roadways that had no traffic? The author sees no reason to be disturbed by the relative size of surface maintenance cost, inasmuch as it is assumed that this cost varies in some direct functional way with incremental road user cost.

Mr. Hansen's questioning of the real meaningfulness of the maintenance cost data used in the paper is partly valid in the sense that the data were neither good nor complete in all instances, as stated in the paper. Moveover, the surface maintenance data used in the model were not subjected to powerful analytical techniques. He further states that "Restricting the selection to control sections 'exhibiting a completed surface life' tends to limit the sample to roads with abnormal problems which were reconstructed earlier than the average of all existing sections." If this is true, maintenance cost patterns would be distorted. On the other hand, if the data were ideal the selection of control sections showing completed surface lives would be excellent for ascertaining surface maintenance cost patterns.

It should be stated that the paper represents an initial attempt to apply replacement theory techniques to the problems of highway surface determination. As yet, the model remains crude. It is hoped that in the future constructive criticism by thoughtful analysts will serve to overcome any shortcomings the model may have.