Concepts and Applications of Engineering Economy in the Highway Field

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● ANALYSES of the engineering economy of "for profit undertakings" are well understood and extensively practiced in industry, having reached the age of maturity. In public works understanding and application are far from reaching a desirable maturity. Highways are particularly troublesome. Highways are an in-between activity. They are a direct instrument of commerce and industry, resemble the public utility, are a government service to its people, and they affect the whole nation, through economic and social factors. Beyond all of these characteristics, there is a definite public policy supporting highways through a tax system that applies, not to the people generally, but to the specific users of highways in accordance with their use, or the value of their use. Thus, there is an analogy with sales in industry, if it is considered that the user pays a price for his highway service.

Because of these peculiarities, it is to be expected that highway administrators and highway engineers are in a quandary about certain aspects of the economic analysis of proposed highway facilities. The highway engineering profession has been long ready for a thorough searching discussion of the principles, theories, procedures, and interpretations involved in these economic areas.

Although such factors as interest rate, time value, comfort, and convenience, and benefits and losses to business are important factors, there is no intention of discussing herein their appropriateness, or the choice of numerical values. Brief comparison is made of the rate-of-return solution and benefit-cost ratio solution, and a few other technical aspects. Although the intention is not to take sides on items in controversy, some of the attitudes and concerns of the author will be expressed.

NATURE AND OBJECTIVES OF ECONOMIC ANALYSES

From Grant's previous paper one can readily and justifiably conclude that the one basic objective in making an engineering economy analysis of a proposed facility is to determine whether the anticipated monetary benefits will justify the monetary cost. All of the principles, procedures, and theory applicable to engineering economy studies for private industry also apply to all forms of public works, including highway facilities. Management's decision to go ahead with the proposal or not to go ahead may also be based upon other factors, but usually the economic analysis is the factor frequently given the greater weight. Public officials may place greater weight upon intangibles or factors not closely related to monetary benefits than do the officials of private enterprise. In private industry the immediate or longtime economic consequence is the main determining factor.

In both industry and public works, final decisions may not be wholly money based, but the economic analysis itself is wholly money based. That is its purpose. It should not include other factors not readily and reliably money based. It is highly important to keep in mind when making an analysis for engineering economy of highway improvements that such analysis is to determine the economic consequences only. It is not related to the method of financing. Financing is something separate and may be analyzed after the economics of the proposal have been determined. The economic results, however, bear strongly upon the decision whether to finance the proposal. Why else do bankers insist upon a rigid analysis of the economy of any proposal they may consider underwriting? Public works and highways are as important to analyze from the viewpoint of the money value of benefits and costs as are proposals for profit-making private ventures. This is true even though in the end the final decision is based upon social, educational, or other non-economic factors.

Analysis of the economic benefits to be obtained from a proposed highway facility as related to the economic costs of the facility could be made for the following specific objectives:

1. To determine whether the facility is economically justified.
2. To aid in the choice of engineering features of design.
3. To offer one means of determining priority of one highway facility as related to others.
4. To assist in tax or cost allocation studies or decisions.
5. To develop information which would aid in evaluating a specific highway proposal as against other proposals in public works or community projects.

The analysis for these economic consequences involves such factors as: motor vehicle operating costs; time value of individuals; safety of individuals and property; changes in the economic value of land, buildings, business, and resources; economic cost of capital investments; and maintenance and operating costs of physical property.

Economic analysis is economic, not social, not political, not financial. Only those factors which can be reduced to supportable and realistic dollar values should be included. Educational, defense, social, and general community values should be given such weight as they deserve by consideration outside the economic analysis.

HIGHWAYS COMPARED WITH INDUSTRY

For each economic factor in private industry which bears upon the economic wisdom of making an investment there is usually to be found the same or a comparable factor in highways. Although in quality the factors may be the same, frequently they are assigned different quantitative value or they may be given different weights.

Private industry makes decisions which affect its commitment of capital to the production of goods and services. At the same time it controls production, price, and distribution. In other words, industry has full control over its entire activities. In highways, the highway official does not have full control. The highway official is responsible for commitment of public resources to investment in highway facilities; but the highway official has but little control over the use of these facilities, nor of the price to be paid for their use. The services and goods produced by private industry are purchased by consumers in accordance with their personal choice. Although highway users may have a choice on occasions to go or not to go, they have little choice in their routing, in the quality of the highway facility to fill their particular needs, nor the price (tax) they pay.

Industry has production cost (including sales and distribution expense) and sales income as its two basic factors on which to base capital investment decisions. Industry is not concerned with the adverse effects of its decisions upon its competition, nor is it concerned with the adverse consequences in other economic and social areas of the country. Public officials directing a highway improvement program, however, must not ignore the adverse consequences of highway improvements upon other forms of transportation or upon other economic and social areas. Although these consequences cannot be measured with any high degree of accuracy in an economic sense, still, they must be given consideration. When public resources are committed to highways, such resources are not available for any other activity, public or private.

Private industry has sales which measure day-by-day use and success of the product. These sales in combination with the cost of producing the sales result in a profit and loss statement. Thus, it is comparatively easy to measure the economic consequences of capital investments in industry. Highways on the other hand do not have easily measured "sales." Reliance must be placed on an estimation of benefits derived from the cost of moving motor vehicles over the highway and to the personal benefits enjoyed by the persons transported. Fuel tax and license fee revenues must be considered as sales income, particularly when measuring monetary solvency of a highway. However, many highway improvements are constructed to reduce fuel consumption; in this light, the "sales income" would be reduced by investing in a new highway. As measures of the profitability of highway improvements, motor vehicle operating costs, accident cost, value of time, and general community economic consequences are analyzed.

This general comparison of industry and highways brings out the importance and difficulties of reaching sound decisions on capital investment in highways. Highway facilities are non-usable for purposes other than for highway transportation. Any error in judgment on the commitment of funds is a long-lasting, inalterable error.

HIGHWAY VS OTHER INVESTMENTS

The decision to commit public resources to the construction of a highway facility is a form of capital budgeting. Highway officials make such commitments in their belief that such investment is in the public interest and that such commitment is economically sound; that is, the economic consequences justify the commitment of the capital. Frequently, there are social factors involved which may contribute a certain weight to the decision.

When the highway official commits tax resources to a highway improvement, he has created three situations. The monies commited to the highway improvement are not thereafter available for commitment to: (a) educational facilities, fire or police protection, recreational developments, or other public works or public function; (b) private business ventures; and (c) personal pleasures, needs, or satisfactions.

In making this commitment to highways it is essential, in the interest of public welfare, to determine that the highway improvement will render benefits of greater value than will commitment of the same monies to other public works or private ventures. The resources of the public are limited. Monies spent to build highways can not build schools, churches, and swimming pools; or provide more police and fire protection, or a better home or extended vacation.

In commitment of public resources to highway improvements, it is compelling upon the public official to determine (a) that highway improvement is the highest and best use of the resources available, and (b) that the specific project to be built is the one that will return to the public the highest return or that it will render services of greater importance than any other highway service that could be rendered at that time.

Comparing the need for highway improvements with the need for school facilities and parks is somewhat like making a personal choice between committing the family income to a vacation trip or buying new furniture. Nevertheless, similar decisions are made daily by families and yearly by city councils, boards of education, legislatures, and the Congress.

Knowing the economic consequences of a proposed highway facility will permit administrative boards to make decisions of greater potential correctness, than can be made without the advantage of economic analysis.

Industry is not confronted with the value of time simply as time. Time reductions or time increases brought about through the betterment of procedures and equipment result in decrease or increase in unit cost of production. In highways, a saving of time is frequently at increased cost of motor vehicle operation. The saving of transportation time probably results in increased vehicle-miles of travel, but here again there is no way to measure the benefit or profit of increased travel. The time saving of motorists probably is devoted to some activity other than increased travel. The value of time is a critical value in the economic justification or comparison of proposed highway projects.

In industry usually there is a minimum of intangible values to consider. It is true that industry must consider the effect of proposed changes upon employee morale, public relations, and the like, but generally speaking, decisions are almost wholly based upon economic considerations. In highways, transportation has great effect upon education, social exchange, health, recreation, community pride, and national defense. It is difficult to put a monetary value on any of these benefits. Therefore, it is probably best to leave all such elements out of economic analysis and let them be weighed at the end in accordance with the judgment of the officials who must make the final decision. These extra non-user benefits are consequences of the highway improvement which should not be permitted to cloud or merge with the economic factors which can be easily isolated and priced.

PRINCIPLES OF RETURN ON INVESTMENT

For long ages, the managerial principle controlling business decisions has been that a reasonable return on investment, commensurate with the risks involved, is not only desired but is something the investor must expect or he would not invest. Money is invested in private business to earn dividends or returns. The same principle is applicable to public enterprise, though frequently it is difficult to measure the returns in monetary symbols.

There is no foundation for the conclusion that public enterprise can justify a lesser return than investment in private enterprise, the risks being comparable. There is no justification for the conclusion that a public enterprise of comparable risk should earn only 3 percent, whereas in industry it would be permitted to earn a 10 percent return. Lower interest rates and returns in public works as compared to private industry are used because of the lesser risk.

Risk, in private capital, is the uncertainty that the investor will (a) get back his original investment, and (b) a fair return on his investment. These two elements, in turn are measured by the degree and speed that changes in the arts and customs take place, and the continued acceptance (purchase) of the product by the customers.

Since highways are operated without a system of cost accounting and without specific sales income, there is no positive measure of the risk factors of return of and return on the investment. But these risks do exist. The degree of risk in highways can be expressed by the uncertainty of the number of years of useful life of the facility and the uncertainty that the traffic will develop in volume, character and running cost as predicted. In other words, the economic analysis is based wholly on predictions of costs and benefits. The uncertainty that these predictions will materialize is the risk involved. When 50 years is used as the period of analysis, it means that the facility should render the service for at least 50 years, and that the benefits would have to continue for 50 years as forecasted or in greater amounts for fewer than 50 years.

Throughout the history of highway development, there has been a comparatively high rate of obsolescence, inadequacy, and physical wear and tear. There have also been great changes in modes of transportation from the pony express down to the monorail and jet-powered airplane. The electric interurban railway and the street railway have come and gone. Even railroad passenger service is on a rapid decline. With this history, what justification is there in economic analysis service lives of 50, 75, and 100 years for elements of the highway? Yet analysis after analysis of the economic justification of highways, or the selection of elements of engineering design, have been made using such long periods. It is particularly alarming when these long lives are combined with low interest rates of 2 and 3 percent in calculating the annual cost of owning and operating highway facilities.

Industry is quite prone to use 1 to 5 years, and occasionally 10 years as the length of time over which sales or reduced operating cost will produce sufficient return to pay for the entire capital investment plus a return of 10 to 20 percent. Because of the nature of highways and certain other forms of public works, longer periods of analysis and lower rates of return can be used than industry does, but shorter life and higher interest than many analysts are using.

Although private industry will use short life and high rates of return in their economic analyses, it does not follow that their cost accounting sets up depreciation rates based upon these short lives. In cost accounting they use service lives based upon their best estimate of the number of years that the property will remain in useful production.

A similar procedure should be followed in the economics of highways. That is, economic analyses should be made with conservative lives or analysis periods and rates of return comparable to what the public is paying. In cost accounting for highway transportation, service lives should be used in accordance with the best estimate of the number of years the facility is likely to remain in profitable use.

Highway officials must recognize the degree of risk in the construction of highway facilities. The longer the period of time required to produce economic justification of a specific highway improvement, the greater is the degree of risk that such economic consequences will be favorable. Almost no one would commit his private capital to an

investment (not stock or bonds) that would require 50 years to pay out without opportunity to sell in the meantime even at a high rate of interest of 8 percent.

Because of the rapidly changing social, economic, and physical environments, the uncertainties of the future are great. We must be concerned about the risk of the distant future and be more willing to forego probable long-term benefit in favor of the more realizable short-term benefits.

FACTORS INCLUDED

The factors and their consequences involved in the economic analysis of a proposed highway facility may be grouped as follows:

1. Consumption or conservation of physical goods and natural resources.
2. The use of time by individuals.
3. Value of non-highway property, goods, and services.
4. Mental and physical condition of the traveler and personal consequences of his choice of route.
5. Other factors, preferably not included in the solution — social life, environment, political organization, esthestics, recreation, pleasures, scenic view, and other intangibles.

Groups 1 and 2 factors may be more or less readily converted to dollar values. They are also distinguished by the fact that resources — goods and time — are consumed. Main items are motor vehicle running costs, goods consumed because of accidents, and the time of driver and passengers during travel.

Group 3 factors are economic insofar as they pertain to dollar values, but differ from Group 1 and 2 factors because they merely represent a change in the market value of property or business opportunity. Initially, they represent only "paper" values, since the real net consequence of gain or loss is not realized until the property is transferred in ownership. These factors cover widespread geographical areas, thus, making it difficult to determine all plus and minus changes from which the net consequence is obtained.

Group 4 factors are intangible insofar as they are not physical property, are not services, and are without any standard means of measurement as to their existence or as to their monetary worth.

Group 5 factors are those consequences of highway improvements which are difficult to trace solely to highways, which are without means of direct measurement, which have no accepted unit by which to evaluate their worth, and which are of general community interest rather than specific to individuals. The factors in this group are best considered as extra-market consequences outside the economic analysis and given such weight as may be just and right in each case by those officials who have final responsibility of approval of improvement projects.

The analysis should be arranged in parts so that the money-based items of real tangible character (Groups 1 and 2) are separated from the intangible items money-based purely by assumption of unit values. Time value is preferably separated from motor vehicle operation.

The economic analysis of a specific proposal for a highway improvement, requires two basic decisions: (a) selection of the economic factors to include in the analysis, and (b) selection of unit dollar values to assign to each economic factor to be included in the analysis.

Since the analysis is to determine the net economic consequences brought about because of use of the proposed facility, each factor included must be an economic one. To ascertain that a factor is economic in result, its true character and end result in the economic system are explored. Are goods, supplies, and resources consumed in the use of the facility? If their consumption is reduced can these goods, supplies and resources be used to economic advantage elsewhere? Is the time devoted to travel of economic value? If the travel time is reduced or increased does this increment of change have economic value? To what profitable use will the time be applied?

Do the social and economic systems permit of assignment of economic values to

impedance, comfort, convenience, pain, misery, pleasure, mental anguish, and other personal factors? Is it in the best interests of the public to base the construction of highway facilities upon the value of time, the value of personal comfort and choice? Similarly, for changes in land and business values.

Even after the factors to include in the analysis are chosen, there remains the difficult task of assigning units of measurement and unit values to these units. Material goods are generally valued upon market conditions. But this process is still uncertain with motor vehicle operations, because there is a wide void in knowledge of vehicle performance and consumption of fuel, rubber, and a vehicle as a whole, under specific conditions of speed, gradients, curves, stops, and constant speed vs variable speed driving.

The value of time to the highway user has not yet been systematically evaluated, so assumed values are used. The personal items of impedance, comfort, etc., when used, are based entirely on assumption without any guide, whatsoever. The general practice for time and personal factors is to follow along with unit values with what some other person used. Thus, each subsequent analyst cites a prior authority.

A highly important consideration, so far only alluded to, is the necessity of eliminating duplications and overlapping of the several economic elements. What is involved in the final solution is the "net economic consequence." Often, a gain is accompanied by a loss. Time is gained by higher speeds, but vehicle running costs are increased; time is saved by routing around delays, but at an increase of distance; land values adjacent to a highway facility are increased, but farther away they are decreased; business activity is greatly increased along the new route; but decreased (or fails to locate) elsewhere; highway travel is increased; but expenditures for luxury goods and other pleasures are decreased. One community may lose business and tax income which is actually transferred to the adjacent community as a gain. These duplications and overlaps can be avoided only by careful and systematic scrutiny of each factor and its unit value.

CRITICALNESS OF CERTAIN FACTORS

Such factors as interest or rate of return, service life or analysis period, unit motor vehicle operating cost rates, intangible factors such as time, impedance, comfort, and convenience will prove that most any quantitative answer can be obtained if one desires to manipulate these factors between their minimum and maximum values.

In a comparative analysis of two proposals, the improved highway may reduce motor vehicle running cost by 1 cent a vehicle-mile. As an added factor, if 0.5 cent per mile is allowed for comfort and convenience, the benefits are thus increased by 50 percent. Similarly, if $1.50 an hour is taken as the value of time as compared to $1.00 an hour, the benefits of time saved are increased 50 percent.

An illustration of the magnitude of these factors and their influence is given in Tables 1, 2, and 3. Table 1 gives the total cost of motor vehicle running costs and value of time for a typical relocation of a primary 2-lane highway from a location through the city to south of the city. Table 2 gives the increase or decrease in these costs on the new location as compared to the old city route. The value of the factor of comfort and convenience at 0.5 cent per vehicle-mile is also shown.

The motor vehicle benefits (savings) are only $33,934 as compared to a time value saving of $705,885. Here is a case where one factor — motor vehicle costs, only 4.6 percent of the total — can be worked out within reasonable degree of refinement and closeness and the other factor, 95.4 percent of the total, is based wholly on a judgment value. Where time is a factor it will usually far outweigh motor vehicle costs because, at $1.35 per hour, its value is 2.25 cents per mile at 60 mph. Few projects will decrease motor vehicle running costs as much as 2.25 cents a mile.

Important also, is the personal factor of comfort and convenience. At 0.5 cent per mile this factor amounts to $96,618 for this relocation of route. This sum is almost three times the reduction in motor vehicle costs.

Table 3 indicates a wide variance in annual highway capital costs as interest rate varies and as the number of years used in the analysis varies. Each of these two values are chosen by judgment. The range in capital cost is from $41,765 at 2 percent and 100 years to $211,428 at 10 percent and 20 years.

TABLE 1

MOTOR VEHICLE RUNNING COSTS AND VALUE OF TIME

Vehicle Class	Vehicle-Miles per yr	Vehicle Running Costs		Value of Time	
		¢ per mi[1]	$ per yr	Hours of Travel per yr	Value $ per yr[2]
A	B	C	D	E	F
(a) Old Route Through City					
Passenger cars	16,472,815	3.875	638,366	721,017	973,373
Single unit trucks	1,869,895	6.851	128,113	93,380	196,098
Combinations	981,120	18.817	184,616	53,594	141,488
Total	19,323,830	—	951,095	867,991	1,310,959
(b) New Route, South of City					
Passenger cars	14,256,170	4.534	646,416	340,892	460,204
Single unit trucks	1,556,725	7.669	119,392	40,529	85,111
Combinations	771,975	19.606	151,353	22,636	59,759
Total	16,584,870	—	917,161	404,057	605,074

[1] Quotient of Column D divided by B. Column D calculated from unit costs on level tangents, horizontal curves, gradients, and stops by speeds.
[2] Based on rates per hour of $1.35, $2.10, and $2.64 for cars, trucks, and combinations, respectively.

Too often the critical factors of time, personal comfort, interest rate, and period of analysis are chosen without serious consideration of their effect on the final answer. Frequently too, the final report upon which the public official bases his decision does not disclose these factors and their values. Only benefit-cost ratios are reported.

In contrast with industry, the current, most frequent highway economic analyses have to do with selection of alternates for a project already accepted for construction. Thus, the solution for choice of "with or without" — economic justification of constructing or not constructing the project — is the infrequent solution.

Fortunately, as of today in route location solutions, the choice of factors and their values — motor vehicle operating cost, value of time, and others — does not influence the choice of project greatly because the factors have about the same weight and influence in each alternate considered. Nevertheless, effort needs to be made to seek correct factors, proper values thereof, and to apply them correctly. To this end, study and research should be directed.

TABLE 2

BENEFITS IN MOTOR VEHICLE RUNNING COSTS AND IN SAVING OF TIME — NEW ROUTE OVER OLD ROUTE[1]

Vehicle Class	Motor Vehicle Running Cost, $ per yr	Value of Time $ per yr	Total	Comfort and Convenience at 0.5¢ per mi, $ per yr
Cars	- 8,050	513,169	505,119	82,364
Single unit trucks	8,721	110,987	119,708	9,349
Combinations	33,263	81,729	114,992	4,905
Total	33,934	705,885	739,819	96,618

[1] From Table 1.

TABLE 3

ANNUAL HIGHWAY COST AT SEVERAL RATES OF INTEREST AND ANALYSIS PERIODS

Interest Rate (%)	Annual Capital Cost ($)				
	20 Years	40 Years	60 Years	80 Years	100 Years
2	110,083	65,801	51,782	43,290	41,765
4	132,448	90,941	79,564	75,265	73,454
6	156,933	119,632	111,377	109,031	108,319
8	183,334	150,948	145,436	144,306	144,065
10	211,428	184,066	180,594	180,088	180,013

Notes:

Total construction cost including ROW and engineering – $1,800,000.

Annual maintenance, operation, and administration – $18,000.

Add $18,000 annual operation and maintenance to capital cost to get annual highway cost.

PROCEDURE OF ANALYSIS

The exact step-by-step procedure to follow in the economic analysis should not affect the final answer. Yet, the final answer may be more easily achieved and may be interpreted to better advantage under one procedure than another.

The procedure of analysis is one in which the primary objective is to compare highway cost plus motor vehicle costs plus other costs for one condition (say the existing one) with the same cost elements for one or more proposals for new facilities.

$$T = (C+M+H) + (V+A+T+P) + E$$

in which

T = Total annual cost, incurred in moving the vehicles over the project;
C = Annual capital cost of the highway;
M = Annual maintenance cost of the highway;
H = Annual headquarters, administration and operation cost;
V = Annual cost of vehicular operation;
A = Annual cost of traffic accidents;
T = Annual value of time of transportation;
P = Annual personal value of travel (comfort, impedance, strain, etc.); and
E = Other economic costs.

It is not to be assumed that each of these factors is to be included in every analysis, but they represent specific factors that have been used by certain individuals.

The final answer of the economic consequences of a proposal or group of alternates is more useful to those top officials who are required to make the final decisions when separate answers as well as the grand total, are presented for such factors as (a) motor vehicle costs, (b) value of time, (c) comfort and convenience, impedance or other personal factor, and (d) community factors pertaining to non-user consequences. In other words, these factors are to be combined at the end rather than at the beginning of the analysis. Separate calculation and reporting of these factors permits of according them different weights in the final analysis.

Consequences as a result of growth in traffic should be separated from current traffic because of uncertainty, necessity of discounting benefits from the future to the present, and the fact running costs are not subtractable from the costs of existing traffic to arrive at total benefits.

The analysis of economy is best handled procedurely, by computing costs and values

TABLE 4

CALCULATION OF RATE OF RETURN, BENEFIT-COST RATIO, AND CORRESPONDING INCREMENTAL SOLUTIONS

Plan	Constr. Cost ($1,000)	Annual Cost ($1,000) Capital[1]	Oper. and Maint.	Highway Col. 3 + Col. 4	Veh. Oper.	Total Transp. Col. 5 + Col. 6	Benefits ($1,000) Annual 500-Col. 6	Net Annual Col. 8 - Col. 4	Rate of Return[2], (%) Col. 9 ÷ Col. 2	Benefit-Cost Ratio Col. 8 ÷ Col. 5
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
P	—	—	60	60	500	560	—	—	—	—
A	1,800	91.8	50	141.8	200*	341.8	300*	250*	13.89	2.12
B	1,500	76.5	45	121.5	205	326.5*	295	250*	16.67	2.43
C	1,300	66.3	43*	109.3	220	329.3	280	237	18.23	2.56*
D	1,200	61.2	50	111.2	225	336.2	275	225	18.75	2.47
E	1,000	51.0	55	106.0	250	356.0	250	195	19.50*	2.36
F	800	40.8	70	110.8	280	390.8	220	150	18.75	1.99
G	700*	35.7*	65	100.7*	300	400.7	200	135	19.29	1.99

Incremental Solutions		Rate of Return (%)	Benefit-Cost Ratio
Plan A/Plan G	= 115/1,100	= 10.45	100/41.1 = 2.43
Plan B/Plan G	= 115/800	= 14.37	95/20.8 = 4.57
Plan C/Plan G	= 102/600	= 17.00	80/8.6 = 9.30
Plan D/Plan G	= 90/500	= 18.00	75/10.5 = 7.14
Plan E/Plan G	= 60/300	= 20.00*	50/5.3 = 9.43*
Plan F/Plan G	= 15/100	= 15.00	20/10.1 = 1.98
Plan A/Plan E	= 55/800	= 6.88	50/35.8 = 1.40
Plan B/Plan E	= 55/500	= 11.00	45/15.5 = 2.90
Plan C/Plan E	= 42/300	= 14.00	30/3.3 = 9.09*
Plan D/Plan E	= 30/200	= 15.00*	25/5.2 = 4.81
Plan A/Plan D	= 25/600	= 4.17	25/30.6 = 0.82
Plan B/Plan D	= 25/300	= 8.33	20/10.3 = 1.94*
Plan C/Plan D	= 12/100	= 12.00*	5/negative
Plan A/Plan C	= 13/500	= 2.60	20/32.5 = 0.62
Plan B/Plan C	= 13/200	= 6.50*	15/12.2 = 1.23*
Plan A/Plan B	= 0/300	= negative	5/20.3 = 0.25

[1] At 30 % for 30 years.

[2] Based on first year benefits divided by construction cost. A more precise rate of return would be the rate corresponding to Col. 10 values when considered to be the capital recovery factor.

* Most favorable result.

in every case for every factor and item for each alternate proposal. The difference in these costs are then the economic consequences. Thus, by this system savings or benefits are not computed directly, but they result only by comparison of costs of the alternate proposals considered. This procedure simplifies the calculations, maintains consistency in unit values, and provides direct means of comparing the consequences whether positive or negative.

RATE OF RETURN VS BENEFIT-COST SOLUTION

A few comments on the rate of return and benefit-cost ratio solutions are appropriate. These methods deserve a lengthy discussion to present an adequate measure of their merits and shortcoming, but these comments may be helpful.

Industry uses the rate of return solution and government, generally, uses the benefit-cost ratio. Industry is accustomed to the rate of return or profit concept because its whole structure is based upon profits as related to investment. In government the

benefit-cost ratio is widely used, perhaps largely because of the "green book" of May 1950 (1). This pamphlet sets forth concepts and practices for economic analyses in an attempt to clarify the stipulation in 1936 by Congress that only water resource projects with benefits in excess of costs should be undertaken. In the highway field the benefit-cost analysis is currently popular because it is the basis of the AASHO manual of 1952 (2) now the standard pattern for State highway departments. When correctly handled both the rate of return solution and the benefit-cost-ratio methods produce the correct result, but not necessarily results which would rank several proposed alternates in the same order. The rate of return solution measures the rate of return on the investment after the annual maintenance and other current costs are subtracted from the annual benefits. Thus, the rate of return is dependent on the ratio of annual maintenance cost to invested capital.

The benefit-cost ratio solution is dependent on the interest rate and analysis period assumed in the analysis. It gives an abstract number, difficult for most persons to comprehend and until the basis of its calculation is known, the benefit-cost ratio has little real meaning.

Each method is subject to the incremental analysis, that is, a measure of the desirability of the increments of benefit and of cost between a range of alternates. The economical grade reduction or the culvert size problem are good examples to illustrate the increment concept.

Starting with a grade of 10 percent, it could be that the annual benefits could be greater than annual costs for a reduction in grade down to 0 percent. An incremental, percent by percent, analysis might show, however, that reduction to a 3 percent grade would be in order for at this point an additional dollar spent in grade reduction would produce benefits, the present worth of which would be less than one dollar. Thus, the increments of grade below 3 percent were less in benefits in proportion to costs than obtained by reduction from 10 to 3 percent.

Similarly, when the capacity of a culvert is to be determined in relation to benefits and costs there is a wide range of culvert sizes to choose from. By studying the alternates on an incremental basis the size that maximizes the benefits and returns in relation to cost will be determined.

This principle of incremental analysis is applicable equally well to highway location selection between several alternates.

Table 4, a set of hypothetical data, illustrates the incremental method and gives a comparison of the rate of return and benefit-cost solutions.

Because of the variable ratio of operation and maintenance costs to construction costs, the rate of return solution and benefit-cost ratio methods do not rank the alternates A to G in the same order. Likewise, in the incremental analysis. In the end, however, alternate B is selected by both solutions as being the economical choice.

The rates of return and benefit-cost ratios, columns 10 and 11, are in comparison with the existing highway facility P. These answers do not indicate a comparison of alternates A to G one with the others, but only as compared with the present P facility.

In the second series of solutions the comparison is with alternate G. A comparison with E is next made and finally comparisons are made with C and B. Alternate B, the final choice reached by both methods is the one that has the lowest total annual transportation cost, column 7.

Should the analysis by increments not have been made, the choice would have been alternate E by the rate of return method and alternate C by the benefit-cost ratio method.

QUESTIONS FOR RESEARCH

There is need for an intensive and extensive research on practically every aspect of the analysis of the economic consequences of highway improvements. Although the subject has been given attention in the past and analyses are being made today, the total process has not yet reached maturity. There are many misunderstandings about the subject, areas of conflict of opinion, and a lack of factual data on costs and performance of vehicles under specific road conditions. Some of the questions research could answer are as follows:

1. How should each specific type of highway proposal be analyzed? For instance, should urban expressays be analyzed in a different manner than rural expressways? How should an urban widening and resurfacing project be analyzed? What is the proper procedure to follow in determining the economic value of frontage roads?
2. What are the costs of operating cars and specific weight trucks on specific gradients, on horizontal curves, in traffic congestion, at different speeds for each condition, on rough pavements, for each stop from different speeds? What is the influence of lane width and of shoulder width on motor vehicle running cost?
3. By what different types and weights should traffic be grouped for convenience, and yet accuracy, in the analysis?
4. What is the correct consideration to accord future changes in traffic volume? Is generated traffic handled the same as existing traffic? As normal growth traffic?
5. For the economic analysis, just what cost items pertaining to accidents and death are admissible and what unit value is to be ascribed to each item? What are the offsetting items?
6. Whose time is valuable and under what conditions? How valuable is time? Is 1 min each for 1,000 cars as valuable as 20 min each for 50 cars?
7. When and at what price is there value to comfort, to convenience, to strain, to annoyance, to uninterrupted movement, to movement at uniform speed, and to personal preference?
8. What is the nuisance value of dust, of noise, of billboards?
9. Does the change in market value of land and business constitute an includable item? If so how far afield from the highway project are the economic consequences to be measured? Does the change in vehicle operating cost and time value measure the change in value of land and business?
10. What is the answer to the proposal of including any changes in real estate taxes?
11. Can the increase in business and industry along the route be considered a net benefit to justify construction? Or is it just a transfer benefit, or loss elsewhere?
12. Shall education, postal service, fire, police, health, social change, and other community aspects be evaluated and included in the analysis?
13. What is the proper rate of interest or return to use? How should it vary with type of facility?
14. Shall full economic service lives be used or some shorter analysis period?
15. Should recreation, sports, and general pleasure be evaluated and included in the analysis?
16. What value is to be ascribed to national defense benefits?

The economic analysis to justify construction of a highway facility or to select one proposal in preference to others is of great weight. The official having final decision is entitled to have before him an accurate, unbiased, complete analysis based on sound and fully acceptable principles, concepts, and values. By concentrated and diligent search by a group of devoted economists and engineers the foundation of such a high type of analysis will become possible.

REFERENCES

1. "Proposed Practices for Economic Analysis of River Basin Projects." The Inter-Agency Committee on Water Resource, Washington, D.C., Revised (May 1958).
2. AASHO, "Road User Benefit Analysis for Highway Improvement." 917 National Press Building, Washington, D.C. (1952).

Discussion

Van Riper. — You did not refer to savings in accidents. Operation on freeways in comparison to the city street system is a very realistic factor and it should be considered.

Winfrey. — It is mentioned briefly in the paper. However, to the extent that accidents consume resources and goods, they must be evaluated. Certainly, medical supplies

and labor would be in Group 1 that I mentioned; it would be included in the time element, Group 2.

On the other hand, how do you place a unit value on these factors after including them? In connection with accidents, there is a tremendous amount of overlapping which is ignored because people have not thought it through. There are many negative and many positive reactions to accidents. You take a man off the job, for instance. He is not producing, therefore we can say it is an economic loss, but how do you know somebody else did not step in and produce what he would have done? Is there a net loss in production?

For an extreme example, I am not sure a fatal accident is an economic loss. It may be a gain because it gives a job to somebody else. If we take a fatality as an economic loss, what about the savings in future goods which he does not consume because he is dead? Certainly we are saving consumable supplies by letting the person die, so what is the difference between not consuming goods and not driving over the highway? In both cases, one is not consuming goods. We need to do a lot of exploring in those fields.

Newcomb. — Would you suggest killing everybody and save everything?

Winfrey. — Would you say stop using motor vehicles so we do not use gasoline? Why would you not consider saving of food?

Cherniack. — I have three points to bring out. One of them is the fact — and I am paraphrasing now — that tax resources once committed deprive those same funds from being used for public projects, for private projects and for personal projects.

A tax commitment for highways deprives City X of building schools, or deprives Corporation XYZ of building a plant, or deprives City Y from building a park. What I want to add is that that is not quite so, that they are not mutually exclusive (that money spent for highways may bring monetary savings in other areas) that the building of a highway may make safer the journey of children to the schools that are in existence. The building of that same highway may make more accessible the plant of corporaation XYZ, and the building of the highway may make a park more accessible and used, to a greater extent than it is now. Therefore, we are dealing not mutually and exclusively with commitments, but simply with whether we are to attain these same objectives through a tax commitment or through spending by the public or by private persons, etc.

We must take into consideration that in our democracy it is within the wisdom of the legislature to commit these taxes to highways or schools, etc., and we do this in fact despite what we may think about our encounters with legislators.

Mr. Winfrey said that when we are dealing with economic studies, we should mutually exclude social benefits. I maintain that the wear and tear of a car is an economic cost but the wear and tear on the nerves of the driver is also an economic and not a social cost. That is the way the driver makes his living, so the wear and tear on his nerves is an economic factor and it should be brought into the data. The fact remains that you cannot compartmentalize these economic and social benefits. They are intertwined.

The third thing that was said was that analysts or consulting engineers may get any desired results for unit values by playing around with figures. Of course, I violently object to that kind of manipulating. We do have to start with a certain amount of integrity here, but I would say from my own experience that it is possible with adequate and sufficient data and with statistical procedures actually to bring into relief these things and to evaluate these intagibles. The measurable economic benefits are to be viewed as in the analogy of an iceberg where the measurable benefits are the part seen above the water and the unmeasurable are the part we do not see. What we have done thus far is to send down a lead, and we find they are three or four fathoms deep when trying to measure them directly; whereas if we use the physicist's approach and take account of the relative density of ice and water, we would find the surprising result—the unmeasurable values (about 8/9 of the mass of the iceberg is submerged) are far greater than the measurable. So, it behooves us to do a little more digging and assembling of data in order to quantify these intangibles or, as they were referred to, these imponderables.

Winfrey. — Mr. Cherniack, I am going to disappoint you. I am going to agree with you. I did not say that a city could not build schools and parks and highways; I simply said, or intended to say or convey, that the money that they commit to a highway project is not available to build parks or schools. It is committed but they then find money from some other resource to build the schools and the parks. But they cannot do it with that same money committed to the highways, so if they commit money to the highways then they have to find other money to do what they would have done with that money had they not committed it to highways.

Congress struggled almost 9 months with that very same problem. They committed money to highways. They did not have enough for certain other things. They finally came back and raised more money by an increased gas tax. So that is my answer to the first point.

With respect to the second point, I do not in my mind think that my mental or physical anguish is a social benefit or social factor. If you want to consider nervousness or fatigue or mental strain as an economic factor, you have the privilege, but in the end, all I ask is that you show in your analysis that it is economic and in some way it is an economic consequence on the production or utilization or consumption of goods and services.

If you go to the office and produce only six hours work in quantity because you were so physically worn out in driving through the traffic that morning, then we can say the mental strain of driving through the traffic is an economic factor because it reduces production, and the output was lower so it becomes an economic point. But my point is you have to prove it. You cannot just assume it.

On the third point, all I ask is that you do not take this entire iceberg, that which you can see and that which you cannot see and wrap it up and give a single figure for it. I want it presented in two figures so that I know what you have done. Then the top official can use his weighting and judgment as to that imponderable, to that thing he cannot see or feel or measure, or that he cannot put a price on; and then he can give it whatever weight he wants to. But when you wrap it up in one solid iceberg, visible and invisible, then you do not know what to do.

Berry. — Mr. Winfrey, I would like to comment on the example of an interchange problem. With an interchange, as I understand it, you have a considerably greater ratio of annual cost to the annual capital costs as compared with the normal continuing highway project. Therefore, with that greater M over A ratio, you are likely to come out with differences in rankings on a rate-of-return basis as compared to the calculation of benefit-cost ratios. Northwestern University ran a study using actual data from several states and it was on an interchange type of problem that we found this difference. But for the building of projects where you are dealing with normal highway construction and the design standards do not produce much difference between the ratios of operating costs to annual capital costs, the rankings by the benefit cost versus the rate-of-return give about the same values. I wanted to bring out that the example you picked served to emphasize rather than minimize — you could have had the other kind of example.

Hennes. — My first point is to return to this dollar for highways which cannot be used for schools. It is true that any dollar used for transportation cannot be used for any other purpose so if we add this all up we conclude that if we did not spend any more money on roads we would have more for schools — which is not true. This gets back to net consequences of highways. There is a net consequence of this improvement that is over and above the choice between the different outlets for investment.

The second thing goes to the economic life. You mentioned how many highways, 50 or 75 years ago, are still in service. Perhaps I am twisting your words somewhat. I think this stems back to the disadvantage of putting economic value on the elements rather than the improvements. There is no route that was in existence 50 or 75 years ago that is not in use today.

Winfrey. — I know routes that are growing up with timber. You can't say they are all in use.

Hennes. — This is a question of fact. In my own state there are about 60,000 miles of

roads. This is about the same now as it was 60 or 70 years ago. The difference has been that as transportation developed and highways developed the need for improvement changed and some routes that got overloaded were replaced as primary routes, but they probably still are carrying as much traffic as the people conceived they would have at that time. Certainly the pavements have been worn out but this is not so much obsolescence as it is deterioration.

Finally, in your comparison between the benefit cost and the rate of return, is it a fair conclusion that in choosing alternatives the use of the total annual transportation cost would give you the correct result; and that, having chosen between alternatives by means of the total annual transportation costs, then for that particular example one could determine its justification by either benefit-cost or rate of return and get fair results?

Winfrey. — I will answer the last question first. I would say the answer is yes. If you take alternates A, B, C and D, and on a comparable basis determine the annual total costs of these highway projects, you select the one with the lowest annual transportation costs — vehicular costs, capital costs, and operating or maintenance costs — provided they are comparable in their service. You would get the same answer by selecting one which has the lowest annual cost of transportation. You get the same one by the benefit cost ratio solution and the same one by the rate of return, so you do not need to go through the other two if you pick on that basis.

Hennes. — Unless because of risk of error.

Winfrey. — Yes, but my point is they both have to deliver the same service. If one takes care of 10,000 vehicles and the other one only takes care of 8,000 vehicles, then you cannot do it because they are not comparable and annual costs will not be comparable because you are dealing with different traffic volumes.

Moskowitz. — The whole reason for making these analyses is that they do not provide the same amount of service. If they did, all you would have to know is how much service they provide, period. In answering Professor Hennes, you just stated that this method was all right provided this existed, that you did provide the same amount of service. Well, what are we here for, then?

Winfrey. — Why do we have that word "if" in our language if it is not to be used in such circumstances?

Moskowitz. — Our whole problem is to decide between alternatives which do not provide the same service.

Winfrey. — There are plenty of variations in location and design where all of the services or results are not comparable, but I will agree with you completely that in many of your highway location analyses, particularly on the Interstate System, there are proposals A, B, C and D and they do not give you the same service. Under those circumstances you cannot make the solution on the basis of strictly minimum total transportation costs because you are not comparing like things with like things.

Rothrock. — Suppose you have a corridor in which the present highways now carry a total ADT of 10,000 vehicles between two points, and plan one new location expected to divert 4,000 vehicles from the old, to compare with an alternate which will divert 6,000 vehicles; thus, leaving residual traffic on the old highways of 6,000 and 4,000 vehicles, respectively. Can't you compare the two alternates by using the costs of travel for traffic diverted to each alternate plus the cost of travel for the residual traffic for that alternate?

Winfrey. — In this case you must take the entire travel between points.

Grant. — I am on Mr. Rothrock's side on this, but I would like to make a further qualification, and that is that the interest rate used in calculating equivalent annual benefits or equivalent annual cost savings, and on capital costs on the improvement, should also be the minimum attractive rate of return. If 3 percent is enough both ways, it does not matter how you look at it, and the minimum annual cost, considering highway

costs and user costs and other costs that you are going to consider, will give a more easily interpretable solution than either incremental rates of return or incremental benefit-cost ratios. This is a way of checking, in a great many instances, whether you have loused up your incremental rates of return or incremental benefit-cost ratios.

Hennes. — In the matter of net consequences — the dollar for schools, the dollar for highways — a dollar spent for highways is not available for schools. I say this is true for a specific instance, but when we view this as a whole there are some net benefits left over because without transportation we would all be living on our own acre of ground, etc.

Lang. — I would like to speak directly to that point, the first point that Mr. Hennes made, and what I am going to say applies to the other comments made in rebuttal to Mr. Winfrey's paper. In a very real sense if you look at transportation — and I am thinking now of all transportation, including highway transportation — it does not produce except in one very restricted sort of situation that I have been able to think of. It does not produce anything that we really want, of and by itself. It only produces something which is necessary to the production of something else that we want. The only exception is the very minor one of sightseeing. In this sense transportation may have a very real value, but in all other senses, as far as I can see, transportation has no value in and of itself. The result is that in all of these economic analyses we are concerned with a conservation process. That is, we are trying to conserve resources because transportation does not produce resources of and by itself. If you think about this a little bit I think it is bound to color the way in which you approach all of these economic analysis problems.

Winfrey. — I think that is a very good observation, but we must not lose sight of the fact that if we did not have any highways, we would have something as a substitute for them (other modes of transportation) so when we are speaking of highway transportation, we must not forget that there are other modes of transportation. We have to build these highways on the justification of using them for 75 years — and that is a long, long time. In the meantime, we may have a completely different type of vehicle which requires a completely different type of highway.

Mr. Hennes made one other point that I want to answer. He spoke about the service life — the long life — but there is a decided difference between possible service life and the accepted practical life period used in economic analysis. In industry, when you do cost accounting to determine profit and loss, you use what is judged to be a reasonable economic life of the facility, that is, that period of time that you can afford to use it and make as much money as you would make if you had to substitute for it. When that point comes, we reached the end of economic life of that machine or tool or building or highway.

Now, we do our cost accounting on that basis and the profit and loss statements are on that basis; but when industrial analysts have to make an analysis of the wisdom — of the economic wisdom — of buying a machine or putting on the market a product, or any proposal of this sort, they use a comparatively short period. I say our economic justifications for proposed highway facilities should be analyzed on a short period and not on the total life of their usability. True, we can say land will be here forever but it may not actually be used for highway purposes that long.

Cherniack. — I did not want to let the assertion go by that transportation did not produce anything. Transportation adds place value. Just as manufacturing adds a value so transportation adds a value. Otherwise, we would say management adds no value and does not produce anything. I think transportation does produce values and we have to determine the values.

There is another point that I failed to mention before on this matter of net consequences. I got the implication that in most cases net consequences approach zero; that it is a mere transfer of benefits from one place to another. My studies indicate that whenever you make an improvement such that you divert traffic from one route to another, you not only divert and attract from other routes, but by the same reason, you also generate or add value, so even if you could measure such things you would find manifestations and indications that you do not have a net value close to zero. You have a net value which is usually quite positive.