TRANSPORTATION RESEARCH RECORD
550

Application of Economic Analysis to Transportation Problems

6 reports prepared for the 54th Annual Meeting of the Transportation Research Board

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
Washington, D. C., 1975

Transportation Research Record 550
Price $3.20
Edited for TRB by Marianne Cox Wilburn

Subject areas
13 land acquisition
14 transportation finance
15 transportation economics
52 road user characteristics

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National Research Council. Transportation Research Board.
Application of economic analysis to transportation problems.

(Transportation research record; 550)

1. Express highways–Economic aspects–Congresses. 2. Transportation–Finance–Congresses.
I. Title. II. Series.
TE7.H5 no. 550 [HE336.E3] 380.5'08s [388.1'1]
ISBN 0-309-02456-0 75-41434

CONTENTS

FOREWORD

This RECORD contains 6 papers that examine various aspects of the application of economic analysis to transportation problems.

Winfrey challenges the application of the consumer surplus concept to the analysis of the economy of highway transportation investment alternatives. He then examines only those consequences of highway improvement that have market prices, including highway facility costs, motor vehicle running costs, traffic accident costs, and travel time. The decision-making process is not examined in this paper except for those areas that can furnish the decision maker with a thorough and reliable analysis of the transportation costs for each alternative considered.

Roddin and Andersen describe the result of a survey made of the current state practices concerning highway user economic analyses. The survey was made in conjunction with the researchers' work on NCHRP Project 2-12, Highway User Economic Analysis, the objective of which is to produce a revised version of the 1960 AASHO Informational Report by Committee on Planning and Design Policies on Road User Benefit Analyses for Highway Improvements (Red Book). The results of the survey include information on (a) types of applications of highway economic analyses; (b) scope of such studies, amount of effort expended on them, and the backgrounds of persons performing them; and (c) types of data collected and values used in calculations. Roddin and Andersen conclude with a summary of suggestions derived from the questionnaire on items that should be included in the revised Red Book.

Freeman and Hutchinson present a method of economic evaluation for centrally focused multimodal urban transport corridors that is based on certain principles of the theory of production. Using the techniques described in this paper allows technical and economic characteristics of the modes to be examined in a quasi-continuous way, and this permits a broad range of potential modal combinations to be evaluated.

Batchelor, Sinha, and Chatterjee analyzed the effects of freeways on property taxpayers in Milwaukee, Wisconsin. They found that right-of-way takings for the freeway system resulted in the removal of real estate property with an assessed value of approximately $33 million from the city's tax base. However, a number of benefits attributable to freeway construction were identified. The scope of the analysis was limited to the quantifiable items for which data were available.

Wohl attempts to clarify the ambiguities of the internal rate of return method and the net present value method for analyzing mutually exclusive alternatives. He illustrates more completely and definitively those ambiguities that can occur and attempts to show that the 2 methods cannot be reconciled without additional calculations, which, by definition, go beyond the internal rate of return method as strictly and properly applied.

Miller describes sensitivity analysis as it relates to the flexibility of the computer program. This paper is based on a recently completed Oregon Department of Transportation study of the rate of return method of evaluating highway projects. The paper discusses program flexibility and the methods by which sensitivity analyses have tested the effect of varying the assumptions underlying road-user studies.

CONSUMER SURPLUS DOES NOT APPLY TO HIGHWAY TRANSPORTATION ECONOMY

Robley Winfrey, Consulting Civil Engineer, Arlington, Virginia

The consumer surplus concept is based on the price-demand relationship that states that, if the consumer price of a commodity is lowered or increased, then the number of units sold will be reduced when price increases and increased when price decreases, if all other factors remain constant. Consumer surplus is the difference between the total price paid by all customers and the total amount those customers would have been willing to pay. This paper concludes that the consumer surplus concept has no justifiable application in the analysis of the economy of highway transportation investment alternatives. This paper is related to only those consequences of highway improvement that are market priced: highway facility costs, motor vehicle running costs, traffic accident costs, and travel time. This paper is not concerned with the decision-making process except to furnish the decision maker with a thorough and reliable analysis of the transportation costs for each alternative considered. Traffic volume composition is discussed, and specific attention is paid to generated, or induced, trips. For the time span of years chosen for the analysis of transportation economy, it is concluded that generated traffic (trips that come into being solely because of the reduction of trip costs) cannot be estimated for the analysis period reliably. Furthermore, estimating consumer surplus is not necessary because total transportation cost of each alternative considered is the only relevant factor. The shift of the price demand as highway design or traffic control changes is discussed. This shift cannot be determined either in scope or direction, and, therefore, the net change in consumer surplus cannot be determined.

•IN THE past 10 to 15 years, the economist's concept of consumer surplus has been increasingly applied to highway transportation, usually in the cost-benefit analyses for evaluating proposed capital investments. In an analysis of the transportation economy of proposed highway capital investments, the economist's consumer surplus concept should not be applied.

Consumer surplus, in certain situations, may be useful in evaluating some aspects of transportation. This paper, however, is restricted to the cost-benefit analysis of proposed highway investment alternatives for transportation economy (resource conservation) that produces answers in the form of equivalent uniform annual cost, present worth of costs, benefit-cost ratio, or rate of return when such answers are used as guides to determine whether to invest and what engineering design to use.

I wrote this paper because I felt that highway engineers do not understand the concept of consumer surplus and that economists do not understand the differences between the relationship of highway users and highway transportation and the relationship of consumers and consumer commodities on the open market.

Consumer surplus is based on the idea that customers buy more of a produce solely because of a lowering of its market price. No other factor is involved. In highway use, drivers select their routing and take trips with little or no regard to the cost for a specific trip. They may choose to use a new facility or an improved old one for many reasons. The cost in dollars or travel time may be included or not included in the decision making. Certainly, cost, or price, is not the sole cause of an increase in traffic that may result from a highway investment.

In this paper, the discussion of the application of consumer surplus to economic analysis is limited to determining the transportation economy differences of 2 ways of investing capital or changing the monetary costs of transportation by changing highway design or traffic operations. Thus the costs involved must be priced in dollars. All nonmarket factors, although they are important to decision making, are excluded. A change in the cost of transportation—a decrease or increase in price, P—must be in dollars, and the price must be recognizable by the driver. Under the concept of consumer surplus, this situation exists because usage (or sales) is increased when prices are lowered, if all other factors remain unchanged.

Economic analysis of the economy of improvements to highways is for 2 purposes. First, the improvement is to be evaluated economically. In other words, Will it pay off in reduction of capital and operating costs? Second, engineering design must be evaluated. In other words, What design produces the desired quality of travel service at the lowest cost?

Engineering design in no way can be related to consumer surplus because the alternative designs must be for the total traffic expected and the cost to use each facility regardless of the source of the traffic.

Quantity of use (or of sales in a commercial application), Q, is measured in number of vehicle trips. The commodity purchased at P then is Q trips. In some analyses, distance per trip may increase or decrease with or without a change in the number of trips.

DEFINITION OF BENEFIT

In the literature dealing with analysis of public works proposals for investment of public money, the word "benefit" is used widely but seldom defined. Perhaps some of the misunderstandings in the literature arise because of this. Benefit often is confused with savings, cost reductions, and personal preferences of the driver.

Some of the meanings of the word benefit include:

1. A monetary cost reduction based on market price,
2. Increased personal satisfaction (not priceable),
3. Enhancement of one's personal preferences (not priceable),
4. Improvement in social, economic, and environmental conditions in the affected areas (usually not priceable), and
5. Difference between actual price and a higher price one would be willing to pay.

The discussions in this paper on consumer surplus are related to priceable cost changes (resource conservation) that can be used as a measure of the profitability of the proposal as a transportation facility. Item 1 from the listing is the only item that will be considered.

The other items are highly important and must be considered in the total decision-making process. But unless a factor can be market priced in the same way that highway structure and motor vehicle running costs are priced, then it cannot be merged with highway costs and motor vehicle running costs.

This restriction results in the exclusion of any consumer surplus that is strictly a value concept such as that of item 5. Of course, consumer surplus that results directly from a price or cost reduction is included.

Benefits also may include values that are not comparable in the same dollars as cost or market price dollars. But a value dollar as a willingness-to-pay value is not equivalent in economic value (economic feasibility or engineering design analysis) to a dollar of cost reduction or resource conservation. This statement is true for value-of-transportation time when such a time value is expressed in terms of "willingness to pay." Economy of transportation should be based on resource consumption and not on value or willingness to pay.

CONSUMER SURPLUS

The consumer surplus concept is shown in Figure 1. It is a simple and correct concept as devised, but its application to highway transportation is not so simply or so directly related as is assumed by many engineers and economists. Its use in highway economic analysis may be challenged justly.

Figure 1 is explained according to the consumer surplus concept derived 130 years ago. The price-demand curve D_0 represents the relationship of the price per unit of commodity to the number of units of that commodity that would be purchased by all customers at that price at that time and place. Thus, at P_0, Q_0 units would be purchased. If the price were to be reduced to P_1, Q_1 units would be purchased.

The consumer surplus at P_0 is the area A_0 within the horizontal price line P_0, the price-demand curve D_0, and the vertical price axis. This consumer surplus is a value concept, not a cost or price concept. This concept comes from the fact that some purchasers of the commodity are willing to pay more than P_0, but, because market price is only P_0, these customers gain a value surplus equal to the difference in price they would be willing to pay and the lower price P_0 that they actually pay on the market. This difference is their consumer surplus. At Q_0, some customers buy because the price is slightly below the maximum price they are willing to pay. And some potential customers do not buy because the market price of P_0 is slightly above the maximum price that they are willing to pay. At this marginal price, then, a slight change in market price—either downward or upward—would shift the number of Q_0 units higher or lower. The price-demand curve is a representation of this change in number of units purchased with a change in unit price. Note that at P_0 the consumer surplus that exists is the total area A_0 above the P_0 price line and that this surplus is a value concept. That is, consumer surplus is the amount of total purchase price the consumer is willing to pay less the amount actually paid at market price P_0.

If the market price is lowered to P_1, the number of units purchased becomes Q_1, and the consumer surplus is increased by the rectangular area A_1 and the triangular area A_2. But note that A_1 is an actual reduction in dollar cost to the customers of the Q_0 units, provided that they purchase the Q_0 number of commodities at the new price of P_1. The triangular area of A_2, however, is a value concept for those who purchase the increase in number of commodities of $Q_1 - Q_0$. The consumer surplus of the triangle is attributed to the new customers only. Of course, the total change to the consumer surplus is the sum of the rectangle A_1 and the triangle A_2. But note that A_1 is a cost reduction and that A_2 is an increase in a value concept. The new customers collectively have gained the satisfaction of being able to buy the commodity at a price below the maximum that they are willing to pay, but they have not experienced a reduction in expenditures required to sustain the same level of living. In fact, they spend money for a new commodity (or more for an old commodity), and this money must come from a change in their spending habits. They have to give up one commodity to obtain another.

Strong emphasis must be placed on the basic premise of the economic concept of consumer surplus. First, only the price of the commodity is changed. The commodity must remain at the same quality and meet the same standards. It cannot be "new and improved." Second, the time period considered must be so short that customers and potential customers will not have changed their relative values and attitudes toward the commodity. If such changes occur, then the D_0 demand curve no longer applies. As proof, consider improving the quality of the commodity shown in Figure 1 and holding the price at the same level. When an improved commodity is sold at the same price, more units would be sold. But, with P_0 unchanged, the point for increased sales would fall to the right of Q_0. This means that a new price demand is established. Furthermore, by both improving the product and increasing the price, one can sell more items. In effect, if the quality, serviceability, attractiveness, or utility of the commodity is changed, the result is essentially the establishing of a different commodity and the development of a new price-demand relationship.

The price change must be recognized by the customer (or highway user). If the price change is not recognized, the purchaser (or traveler) would not be buying because of a price change. The fundamental situation shown in Figure 1 is that the increase in numbers of units purchased results from the lowering of the price. Unless this change in price is recognized by the purchaser, there would be no known factor leading to a change in Q.

APPLICATION TO HIGHWAYS

Figure 2 shows how the consumer surplus concept is related to highway improvements when cost-benefit analyses are concerned. It is generally accepted that capital improvements to highways result in lower travel costs and decreased travel time or both to the users of highways when the new and improved highway is compared to the situation before improvement. Such a change in user costs is represented by the lowering of the cost per trip from P_0 to P_1 as shown in Figure 2.

Improved highway facilities, however, usually change the quality of the ride and trip, and therefore may attract new trip makers, more use by old trip makers, or a decrease in the number of trips. Changes in the quality of highway service (comfort, convenience, scenery, view from the road, change of roadside culture, new routing) generally are not priceable on the market. Therefore, they are not reflected in the price reduction from P_0 to P_1. But these qualities, the personal preferences of the users, are reflected in the increase of trips from Q_0 to Q_1. The result is that a new price-demand curve is generated as shown by the D_1 demand curve, which, in effect, applies to a different commodity. Here, there is a departure from the original concept of consumer surplus because changes other than price are introduced.

In Figure 2, the area A_1 still holds as the measure of the reduction in costs to the Q_0 users as effected by the highway improvement. The area A_2 also would be retained as a value measure of the increase in the consumer surplus gained. A new area, however, now must be considered. Because of a shift to the right of the price-demand curve, the shaded area A_3 between the 2 demand curves is added to consumer surplus in the sense of value. The triangle ACD no longer measures the total increase in the value component of the increase in consumer surplus. The added value now is ACD plus the shaded area A_3.

The gain in consumer surplus existing outside the cost reduction rectangle A_1 cannot be measured practically because no way exists to establish the 2 demand curves. Perhaps one can state correctly that point A is properly located on price-demand curve D_0 and that point B is established on demand curve D_1. One point, however, does not establish a curve.

Highway users do not fit consistently into the general concept of consumer surplus. For example, a decrease in price will not necessarily result in additional trips, nor will an increase in price necessarily result in fewer trips. Over the period used in the economic analysis, the personal value of trips changed as shown by the fact that, as traffic volume increased, overall road user costs increased. This also contradicts the consumer surplus concept that states that as unit costs decrease quantity of sales or trips increase.

The price-demand curve for the highway, road, and street user is forever changing with time. During the normal 24-hr day, the price-demand curve changes from hour to hour. During the hours of light traffic volume road user cost is the lowest; at peak hours the cost is highest and the number of trips is highest. Here the unit price is higher, but, contrary to the consumer surplus concept, the number of trips also increases.

In highways, the price of a road user trip is not deliberately lowered or raised by managerial decision. The price of the trip is changed by changing the highway design or traffic-flow conditions. In this type of change, a new consumer surplus situation occurs where any change in the use of a changed facility may result from a cost of trip change or a change in trip character or both. A change in trip quality that results in a change in user attitude toward the trip may be regarded as a change from one commodity product to another commodity, and, therefore, a change from one unknown price-demand curve to another unknown price-demand curve.

Figure 1. Price-demand curve for purchasing a specific commodity.

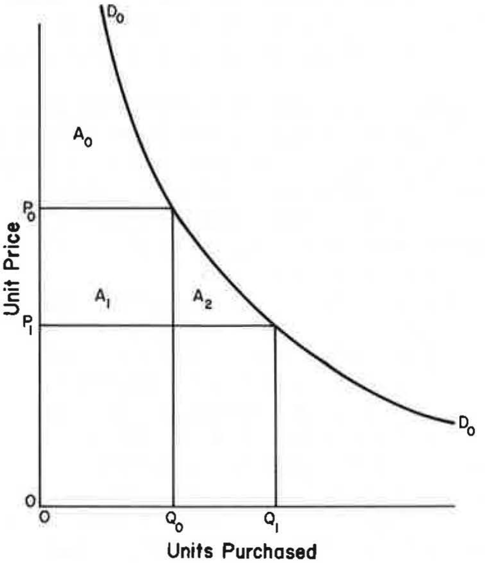

Figure 2. Price-demand curves for highway trips before and after highway improvements.

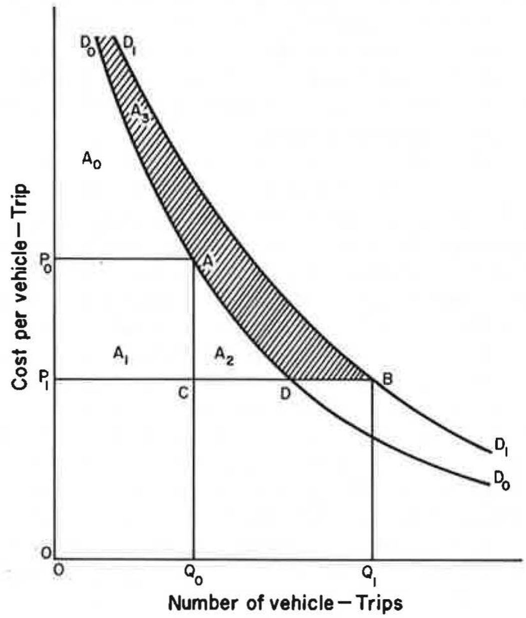

Table 1. Possible effects of highway improvements on price and number of trips.

	Changes in P and Q[a]					
	P minus, Q minus	P minus, Q same	P minus, Q plus	P plus, Q minus	P plus, Q same	P plus, Q plus
Highway Improvement or Situation	A[b]	B[b]	C[b]	G[b]	H[b]	I[b]
New highway at a new location	0-X	0-0	0-X	0-0	0-0	0-X
Reconstruction of existing highway	0-X	0-0	X-X	0-0	0-0	0-X
Widened lanes and shoulders	0-X	X-0	X-X	0-0	0-0	0-0
Added lanes	0-X	X-0	X-0	0-0	0-0	0-X
Widened bridges	0-X	X-0	X-X	0-0	0-0	0-X
Lengthened sight distance	0-X	X-0	X-X	0-0	0-0	0-X
Increased radius of horizontal curves	0-X	X-0	X-X	0-0	0-0	0-X
Construction of grade separations	0-X	X-0	X-0	0-0	0-X	0-X
Railway crossing protection systems	X-X	X-0	X-X	X-X	0-0	0-X
Closing of intersections and access to abutting property	X-0	0-0	0-0	0-0	0-0	0-X
Spot safety improvements	0-X	X-0	X-0	0-0	0-0	0-0
Ramp metering, effect on freeway traffic	X-0	X-0	X-0	0-0	0-X	0-X
Ramp metering, effect on ramp	0-0	0-0	0-0	X-0	X-X	X-X
Directional traffic flow	0-X	X-0	X-0	0-0	0-0	0-X
Intersection channelization	X-X	X-0	X-0	X-0	X-0	X-X
Traffic signs and signals	X-X	X-0	X-0	X-0	X-0	X-X
Lighting	0-0	X-0	X-0	0-0	0-0	0-X
Improved roadway surface or shoulder or both	0-0	X-0	X-0	0-0	0-0	0-X
Roadside beautification, generated traffic	0-0	0-0	0-0	0-0	0-0	X-X
Growth in traffic volume over years	0-0	0-0	0-0	0-0	0-0	X-X

[a]In the entries, the first 0 or X refers to the highway segment on which the improvement is made. The second 0 or X refers to other segments of routes within the network affected by the improvement. The 0 indicates no effects are probable, and the X indicates that some effects are probable. The changes shown at the column headings refer to the combination of change in P and Q.

[b]Consequence class taken from Figure 3.

HIGHWAY IMPROVEMENTS AND PRICE-DEMAND CURVES

For highways, a change in number of trips brought on by a highway improvement is difficult to establish. An entire geographic area traffic pattern may be rearranged by a shift of travel routings. Traffic diverts from one route to others and from one mode to others; new trips are generated; certain trips are discontinued; and relocation of businesses and people caused by highway improvements affects the number of trips, their length, and their purposes.

In analyzing the transportation economy of any proposal to alter existing highway design or traffic control at a spot location, route, or system of routes, one must consider all consequences to road user costs, and, therefore, all traffic behavior whenever these consequences may affect the cost of transportation. An often-expected consequence is that traffic flow will increase after the improvement on the route. This flow increase, to a large extent, will be composed of users attracted from other routes to the newly improved route. And this decreases the number of users of those routes.

For spot improvements to improve traffic flow or decrease traffic accidents, the number of trips may not change, and the users may not be conscious that their costs and travel time are affected. In many improvements to local roads and streets that mainly serve as land access, the number of road user trips remains constant after the road improvement because there is no alternative routing or through traffic. In these cases, despite the lowering of road user costs, the number of trips does not change (except possibly over time and then not because of the road improvement).

The changes in the price-demand curve for highways include 6 of 9 possible combinations of plus and minus changes and no change in both P and Q. These changes depend on the specific character of highway design, the functional character of traffic, geographical location, and whether the change is at a local spot on the highway, a highway route of a mile (1.6 km) or more in length, or a highway system. In the analysis of the economy of transportation, some of these factors are illustrated by the data given in Table 1, which relate the type of improvement to changes in P and Q on the route segment improved and to other network route segments. The amount and probability of changes in P and Q are not indicated.

Figure 3 shows 6 specific classes of consequences, A, B, C, G, H, and I, based on change in price per trip (cost to road user) and number of trips before and after improvements. There are 9 possible combinations of P and Q. The 3 classes that do not change P are omitted in Table 1 and Figure 3 because, if Q is changed, then P must also change, and an improvement that changes neither P nor Q is of no interest here. The price of a trip may be reduced or may be increased. The number of trips may be reduced, remain the same, or be increased.

It is important to keep in mind that the price-demand curves shown in Figure 3 are hypothetical. As stated earlier, the shape and location of a price-demand curve for free public highways under a wide range of uses have not been determined. About all that has been done or can be done is to determine one point for the existing situation and another point for an estimated future condition. Because of a change in the quality of the trip, these 2 points are not for the same set of conditions. The result is 2 points each for a different situation (commodity).

Whether the number of trips over a section of highway increases, stays the same, or decreases as a result of changes in geometric design and traffic control depends on how highway design changes or traffic changes affect the trip distance, vehicle running cost, travel time, accident potential, driver preferences, and alternate routings. The decision of the driver to change to an alternate route depends on 3 main factors:

1. Awareness of highway change;
2. Consciousness of effects of highway and traffic change on running cost, accidents, travel time, and preferences; and
3. Relative costs and satisfactions of alternate routes.

Figure 3. Price-demand curves for before and after values of price and number of trips.

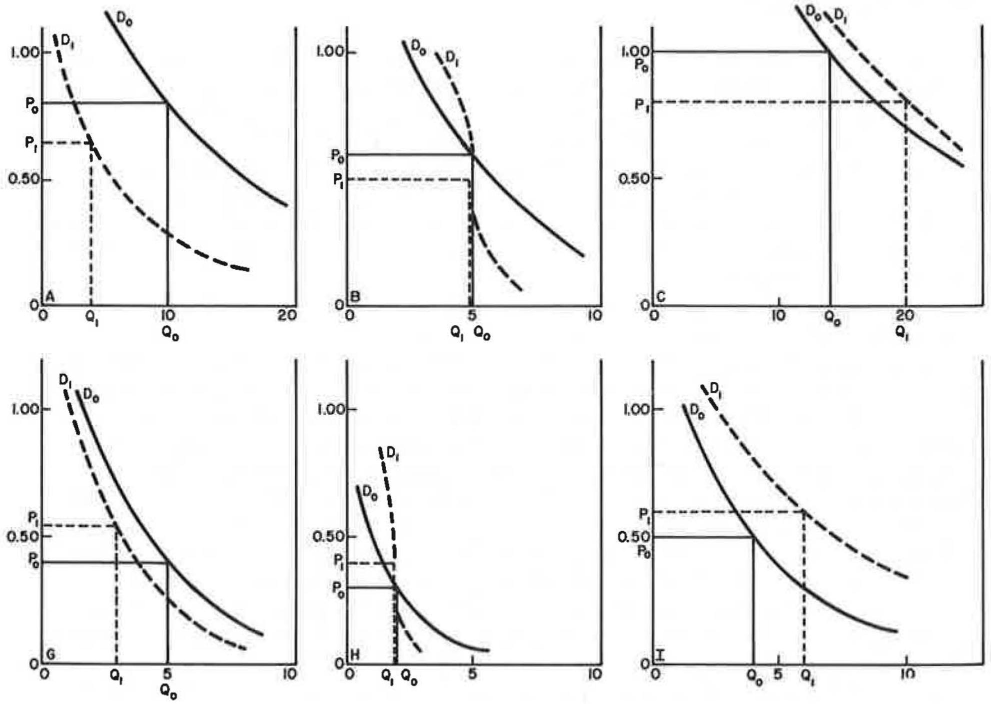

Table 2. Unit costs, number of trips, and user costs on highway segments before and after improvements.

Consequence	Changes in P and Q	Before Improvement: Unit Cost Per Trip (dollars)	Before Improvement: Number of Trips	Before Improvement: Total User Cost (dollars)	After Improvement: Unit Cost Per Trip (dollars)	After Improvement: Number of Trips	After Improvement: Total User Cost (dollars)	Change in Consumer Surplus (dollars)
A	Decrease in both P and Q	0.80	10,000	8.00	0.65	4,000	2.60	1.05
B	Decrease in P and no change in Q	0.60	5,000	3.00	0.50	5,000	2.50	0.50
C	Decrease in P and increase in Q, improved segment	1.00	14,000	14.00	0.80	20,000	16.00	3.40
G	Increase in P and decrease in Q	0.40	5,000	2.00	0.55	3,000	1.65	-0.60
H	Increase in P and no change in Q	0.30	2,000	0.60	0.40	2,000	0.80	-0.20
I	Increase in both P and Q	0.50	4,000	2.00	0.60	6,000	3.60	-0.50
Totals			40,000	29.60		40,000	27.15	3.65
Net change							2.45	+3.65

WHY NEW PRICE-DEMAND CURVES DEVELOP FROM CHANGED HIGHWAY DESIGNS

On any particular route or segment of a route at any given time, traffic volume results from the exercise of driver preferences. Each segment has its own characteristics that are considered by the drivers of vehicles. Each segment competes with other route segments for the driver's choice. These characteristics of the route together with the driver's attitudes toward them establish the price-demand curve for each particular route segment. For these reasons, new price-demand curves are established for routes or segments of routes that undergo design or traffic control changes. This change in price-demand curves also applies to other route segments in the total network that are affected by the improvement.

The consumer surplus concept as applied to use of highways can be related to the purchase of standard commodities on the market and their competitive alternatives. Butter and margarine are competitive foods. Customers have their own price-demand curves for butter and margarine. Price difference and customers' attitudes toward the products are involved. There are users who do not buy margarine regardless of price difference. Other users will not buy butter as long as margarine is lower in price. There are perhaps 20 different varieties of bread available to a customer. These varieties do not have the same price-demand curve to a specific customer because they are not the same product. As with butter and margarine, the many varieties of bread serve essentially the same function as a human food, but there are differences in the quality of their service (nutrition, taste, texture, etc.) and personal preferences. Thus a change in price or quality or both will alter the number of items sold. Changing just the quality of a specific brand of butter or specific brand of bread will alter the quantity of sales; it also will alter the shape and location of price-demand curves.

Highways are the same with respect to their choice of use by drivers. The use of a specific highway route or segment thereof is a result of the characteristics of that highway, the characteristics of traffic on that highway, and the personal preferences of the vehicle drivers. A choice of routes is made with respect to these characteristics.

The characteristics of a route and traffic on that route at any particular time include many factors. Some of the highway design factors include plus and minus grades, horizontal curvature (both number and extent), pavement and lane width, shoulder width, bridge width, pavement smoothness, number of roadside access points, number of intersections, median, access control, and distance. Traffic factors include items such as number and type of traffic control devices, handling of left-hand turns, whether the route is 1- or 2-way, whether it is lighted, traffic mix (number of cars, buses, and trucks), traffic volume, relative speeds and speed changes, relative safety, potential traffic delays, probable driving time, and pedestrian interference. Roadside factors include types and density of roadside structures (residential, business, or industrial); openness of view, which involves height of buildings and width of right-of-way; probability of crime; characteristics of people in the neighborhood and in vehicles; and scenic and historical values.

Considering these 3 groups of factors in total, one finds that evidence exists to expect essential differences in the price-demand curves for specific segments of highway routes and that the people using each segment made their selection according to their personal preferences. When an improvement is made to a specific highway route segment, there is a shift in the total traffic in the affected area, according to these personal preferences. Two significant results come about: (a) traffic mix changes and (b) volume of traffic changes. These 2 changes are found on the route segment improved, other network segments, and connecting and access ways between these route segments. Furthermore, new trips may be generated and old trips may be discontinued on any of these segments or connecting ways.

On existing routes of known traffic volume and mix of vehicles, total user costs are calculated from unit prices of vehicle running costs, traffic accidents, and travel time. These unit costs in no way relate to the drivers' valuations of other factors on which they may have based their preferences for the route segment under study. These unit costs are costs per vehicle mile (kilometer), cost per traffic accident, and hourly dollar values for travel time. However, average daily traffic (ADT) volume is a result of the other factors named in the list of design, traffic, and roadside factors. Therefore, in the analysis of transportation economy, user unit costs are determined for a particular route segment and applied to forecasted ADT segment by segment. The forecaster is assumed to have taken into account all factors that affect ADT after completion of the improvement to the route segment under study and other network segments affected. It follows then that in the analysis for economy of transportation the user costs for both the existing highway and the highway after improvement are calculated by applying to the ADT user unit costs that do not include any allowance or pricing for nonuser factors or factors other than those determined on a unit cost basis for similar highway designs, traffic operations, traffic accidents, and travel time.

Factors other than market priceable road user costs affect both existing and future ADT on all affected route segments. This is why highway improvement to an existing segment results in a new price-demand curve. Also, other route segments that are affected most likely develop new price-demand curves because of the competitive nature of route choices and varying traffic volume and traffic mix as ADT increases or decreases. This shifting of the price-demand curve is shown in Figure 3.

The conclusion of this paper directly contradicts the conclusion of some economists who state that there is no shift in the shape or location of the price-demand curve. Instead, there is an actual lowering of the price in the mind of the user to a level just below the P_1 computed price. In this concept the added consumer surplus may or may not approximate the added area between the two price-demand curves in Figure 2. But, when Figure 3 is examined, the concept is seen to have little validity. Furthermore, the calculation of P_1 is prepared from prior calculations of running cost, accident cost, and travel time, and totally independent of what goes on in the minds of the vehicle drivers.

EXAMPLE

To illustrate the changes in that portion of the total highway transportation cost attributed to motor vehicle use and the changes in consumer surplus that could result from any given highway improvement, a hypothetical example is given in Table 2. The example assumes that (a) the improvement is the reconstruction of a given route segment in an urban area on the same general alignment so that a known existing traffic is contrasted to the situation of new construction on a totally new route; (b) within the highway network affected no new trips are generated, and all old trips are continued; (c) vehicle miles (kilometers) of travel may have changed, but both plus and minus changes are included in the road user cost per trip as given in the assumed data; and (d) for simplification and to hold calculations to a low number, only 6 route segments affected are illustrated, including the segment improved. Figure 3 shows the curves and lines to the scale of Table 2. It should be noted that \$3.65 is not the total change in consumer surplus but is only that area between the P_0 and P_1 price lines and the 2 price-demand curves between these 2 price levels. The change in the consumer surplus area above the P_0 price level (Figure 3) cannot be calculated because the location of the 2 price-demand curves above the 2 price-level lines is not known.

This calculation does not indicate that calculation by the 2 procedures will always give an increase in consumer surplus greater than reduction in user costs. Answers in each case will depend on the relative change in the user unit costs and the change in traffic volume for each of the many route segments affected by the highway improvement. This calculation does illustrate, however, that the location and shape of the before and after price-demand curves must change because of the location of the pair of plotted points, particularly when Q decreases.

Table 2 does not give the before and after total consumer surplus. These values cannot be calculated because complete price-demand curves above the horizontal price lines are not known. Therefore, only that change in consumer surplus that is restricted to the area between the P_0 and P_1 price levels is calculated. These restrictions are more easily identified in Figure 3. It must be kept in mind that the price-demand curves in Figure 3 are assumed. No information exists to determine their shape and direction.

These calculations raise 3 significant problems for calculating change in consumer surplus. First, in segment C, should the improved highway segment have been totally on new location, there would be no known P_0 level or Q_0 for want of any traffic on that segment. In this case, the full price-demand curve D_1 would have to be above the price level P_1 so that the gain in consumer surplus could be calculated. Second, in segment A, if the new price P_1 were extremely high, Q_1 would approach 0 at which point the area of consumer surplus above P_0 would need to be known to calculate decrease in consumer surplus. Third, if the highway improvement resulted in the abandonment of a substantial length of route segment, how could this decrease in consumer surplus be calculated?

One of the principles of economic analysis is that all consequences of a proposal to make a change must be evaluated for whomever these consequences may affect. Therefore, one must calculate the total change in consumer surplus and total change in user transportation costs for the network of routes affected by the proposal under study.

Whatever procedure is adopted should be such that it provides for calculating all changes within the concepts used (road user costs or all changes in consumer surplus) regardless of their magnitudes or their probability of occurrence. The straightforward calculation of the change in user costs for the network affected is possible in all cases, but the change in consumer surplus cannot be calculated for all cases.

REQUIREMENTS OF ANALYSIS PROCEDURE

Highway departments construct, reconstruct, modify, add to, and take away from existing facilities in a number of ways. The analysis procedure must be capable of isolating the difference in transportation cost (and number of trips) or consumer surplus that results from proposed changes in highway design and traffic controls. Consequences of these changes in design and traffic must be determined for the initial, or immediate, time date and for some future period of 5, 10, 15, or 20 years. The procedure of analysis for economy must be applicable to a local spot improvement in the geometry of the highway and traffic flow as well as to rural and urban freeways that affect traffic over a wide area of highway and street networks. For each section of highway, road, or street that may be affected by a specific alteration in highway design or traffic control, estimating the traffic volume and its composition before and after the improvement is fairly reliable. Should, however, the necessity for separating generated (induced) traffic be present, the difficulties and uncertainties would be greatly increased, particularly on a route segment basis.

The situation is further handicapped when the analyst wishes to calculate the change in consumer surplus compared to the change in road user transportation costs. The entire street and highway systems affected by the proposed improvement would need to be identified in terms of the 6 possibilities shown in Figure 3.

Over time, let us say a 20-year period, the situation becomes more complex and defies any reliable analysis of the net change in consumer surplus. People's values of most aspects of living change with time, and this includes highway price-demand curves. Thus travel patterns, cost concepts, and land use changes are altered not because of the specific highway improvement in the past but because of changing technology, customer desires, public works of all kinds, geographic shifts of business and industry, changing government policies, economic factors, and social forces. Also population increases; use of vehicles may increase or decrease in terms of average miles (kilometers) driven per year; urban areas are redeveloped; and new areas are opened up. In the end there is no reliable procedure by which to establish what future traffic may be specifically attributed to the proposed highway improvements.

Generated traffic is an accepted concept, but its identification in practice is beyond any acceptable limits of reliability. Consider the 20-year period following the opening of any new or improved highway facility that lowers the running cost of vehicles, traffic accident costs, and travel time by 20 cents per trip the first year. How can estimates be made for the next year of how many trips will be generated by this 20-cent decrease for the first year? The entire geographical area of n miles^2 (km^2) is involved; land usage, social life, technology, economy, consumption, and transportation of all modes change; and, because of increase in ADT, cost per trip increases. Yet from all of these changes some person is expected to separate total change year by year in number of trips from A to B into trips generated from all other trips. In other words, can anyone estimate the traffic generated today on a given route that was reconstructed 10 years ago, assuming that ADT increased from 5,000 to 9,000?

CONCLUSIONS

If the objective is to calculate the change in consumer surplus, then the areas A_1 and A_2 in Figure 1 give the correct answer. Consumer surplus gained is the rectangle representing price reduction plus the triangle representing value gain to the Q_1 - Q_0 customers. This statement assumes, however, that the price-demand curve is unaltered.

For highways, most analysts follow the same procedure; that is, they add the areas A_1 and A_2 that result from the price-demand curve D_0. To use the full number of trips (Figure 2) Q_1 - Q_0 times price per trip decrease P_0 - P_1 would overestimate consumer surplus by an amount approximately equal to the triangle A_2. This procedure of calculating consumer surplus is correct only if 2 conditions are met. First, Q_1 - Q_0 trips are all induced (generated) by the reduction in cost per trip. Second, the original price-demand curve D_0 still prevails. These 2 conditions are not met, however. Again, if the objective is to calculate the change in consumer surplus, the Q_1 - Q_0 trips must be restricted to generated traffic, and the area A_3 between the 2 price-demand curves must be added to areas A_1 and A_2.

Earlier discussion points out the uncertainties of making any estimate of generated traffic that is separated from other increases in traffic over an analysis period of, say, 20 years. And, of course, area A_3 cannot be estimated because no available evidence exists to establish the location and shape of the D_0 and D_1 price-demand curves. Even if an analyst desired to estimate the change in consumer surplus in accordance with its true concept, any result would be so uncertain that its use would be questionable.

The most uncertain calculations are shown in Figure 3 for making estimates of the changes in consumer surplus on a network basis. For most typical analyses, the consumer surplus change comes from many price-demand curves (Figure 3). Price-demand curves cannot be established for the day the new facility opened to traffic. To establish them for a time 20 years in the future would also be impossible.

All of the traffic increase Q_0 to Q_1 is burdened with the identical trip costs regardless of source, trip purpose, or prior usage of the road system. A procedure of separating generated trips from traffic growth caused by population growth, population migration, and economic changes is questionable. Why base user costs on 100 percent of traffic growth except for generated trips and then use only half the generated trips? Their cost is the same.

It has been reasoned that generated trips could have been taken before the new facility was available, but the reason they were not taken was solely because the cost was higher than the amount the traveler was willing to pay. But on a consumer surplus basis the analyst could use half the trips generated. The consumer surplus procedure, however, gives full acceptance to all other trips. On a cost reduction basis, none of the new trips (generated, population growth, economic change, or social change trips) has experienced a saving in trip cost because no trips were taken at the old cost (cost before improvement). If the analysis for transportation economy can include some new trips (traffic volume growth) over the analysis period, why is it not acceptable to include all new trips?

An analysis of the transportation economy of proposed highway improvements that ignores the consumer surplus concept does not misrepresent the relative economy of the alternatives or their economic feasibility. Introducing consumer surplus in no way gives the decision maker an analysis that is superior to an analysis excluding the concept. The preferred procedure is to ignore consumer surplus entirely and make all calculations on the basis of market cost of transportation. Cost of transportation includes the priceable costs for motor vehicle running costs, traffic accident costs, and travel time.

The consumer surplus concept is rejected for 2 reasons. First, the economy of highway transportation on which to base a decision of economic feasibility should be based on market-priced changes in consumption of resources rather than the consumer surplus concept of value (willingness to pay). Second, in the analysis, net changes in consumer surplus for highway design and traffic improvements cannot be estimated because there are no price-demand curves.

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DISCUSSION

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Winfrey has presented an enlightening and provocative discussion of several important principles appropriate for an analysis of highway transportation economy. His view that the concept of consumer surplus is not applicable in this context is widely shared by others. For example, Wohl and Martin (28, p. 9) conclude: "It is our view that consumer surplus should not be included in any user tripmaking benefit calculations to be used in assessing the economy of public projects." A less positive view is expressed by Walters (52, p. 56) who states: "The consumer surplus criterion is a tool of analysis that must be handled with care and circumspection."

Most highway economy analyses are structured so that they cannot or do not (and probably should not) account for generated traffic. Thus any elasticity of demand for travel is not considered, and the areas A_2, in Figures 1 and 2, or A_3, in Figure 2, are neither quantified nor used in analysis. The road user benefit that is used in a typical analysis is simply the product of the estimated number of vehicles using the facility or system (Q_0, projected on the basis of assumed normal growth trends) times the estimated reduction in user cost (P_0 - P_1). This, of course, is the area A_1 in Figures 1 and 2. However, area A_1 is also the change in consumer surplus if demand is perfectly inelastic. Therefore, because we are commonly constrained to consider that traffic volumes are equal for all mutually exclusive alternatives, we are in fact using the change in consumer surplus as a measure of economic benefit even though we have had no reason to describe it as such.

On the other hand, let us view a situation in which a determination of consumer surplus is the only practicable method of analysis. Consider the case of a penetration road in a country with a developing economy where the road is to afford access to an isolated area that is either undeveloped or has a subsistence economy. Alternatives, in addition to doing nothing, might include several variations ranging from an unimproved trail suitable only for backpacking to a substantial all-weather road that could carry heavy trucks.

It may be expected that each alternate could be represented by a different supply curve, such as S_a through S_e, as shown in Figure 4. Each supply curve would suggest a different price for transport, P_a through P_e, and would intersect the price-demand curve at a different level of demand, Q_a through Q_e. The extent to which the area served would expand production in response to the substitution of a market economy for a subsistence economy would obviously also vary depending on the use of the highway improvement.

It is also possible that the differing qualities of service from the various transport alternatives are sufficiently representative of different products that demand might be represented better by more than 1 price-demand curve, as Winfrey has suggested. However, we believe that this situation is represented more correctly by a single demand curve and a separate supply curve portraying each of the various alternative types of improvement. Note also that the price-demand curve, rather than being concave upward, is convex to represent the relative elasticity of demand for transport where substitution of a market economy for a subsistence economy is an economically attractive possibility, but demand becomes inelastic at higher levels of production because of natural limitations in productive capability.

In any case, it is evident that the analyst in this situation has little alternative except to attempt to quantify the demand relationships corresponding to several points on the price-demand curve and to use a best estimate of consumer surplus to describe the

Figure 4. Supply curves for highway transportation alternatives.

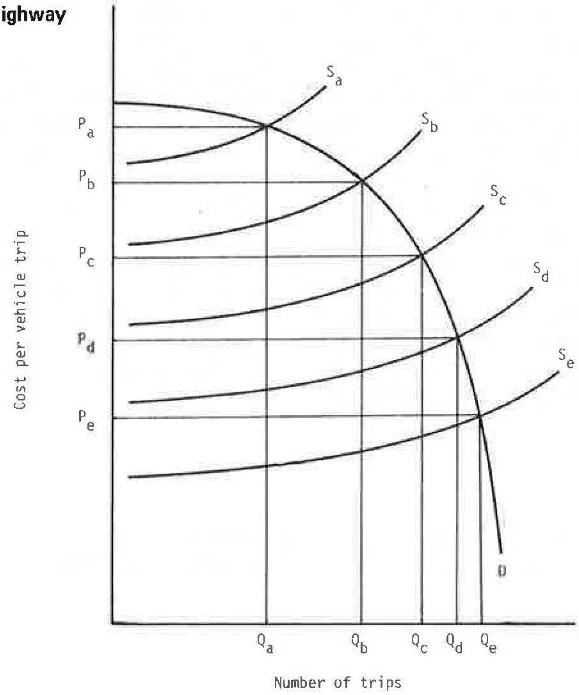
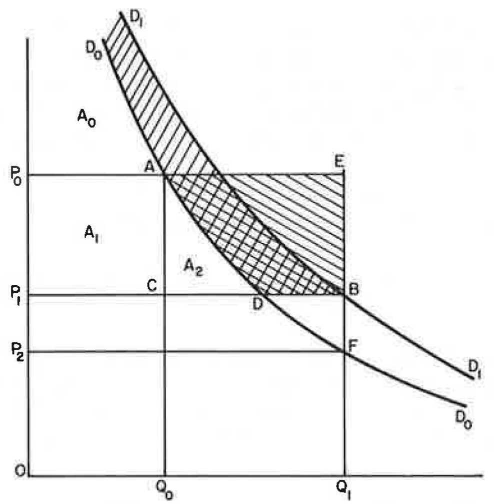


Figure 5. Modification of Figure 2.



benefit. The road user benefit so determined describes a reduction in the cost of transportation even though that transportation might not currently exist because its price is perceived as prohibitive. Nonuser benefits represented by increases in the value of land affected by a transportation improvement are not properly included in an analysis of highway transportation economy, as Winfrey suggested. However, it is reassuring that this benefit, which may be estimated on the basis of precedent for a given country and which has a price determined in the marketplace, should approximate closely the present worth of road user benefits and may therefore serve as a basis for checking the estimated user benefits.

Thus, although it is agreed that the highway transportation analyst typically need not be concerned with concepts of consumer surplus, the analysis will appropriately consider at least the largest portion of a change in consumer surplus. In the less common case of an essentially new highway facility, consumer surplus may represent the only quantifiable benefit, and an understanding of the concept may be essential for an analysis of highway transportation economy.

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DISCUSSION

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We should be very grateful to Winfrey for his clear and penetrating exposé of the concepts embodied in consumer surplus as they should apply to analyses in highway transportation economy. He has highlighted the difficulties of applying the theory in practice and proposed an alternative approach to solving the problem. Winfrey's case against consumer surplus seems to be based on 2 main objections.

1. It cannot be applied in practice.
2. It is not theoretically applicable in any case.

I would like, first, to deal with the second point, which I believe to be unproved and feel to be unprovable. Winfrey states:

> On a cost reduction basis, none of the new trips (generated, population growth, economic change, or social change trips) has experienced a saving in trip cost because no trips were taken at the old cost (cost before improvement). If the analysis for transportation economy can include some new trips (traffic volume growth) over the analysis period, why is it not acceptable to include all new trips?

Winfrey does not believe that one can distinguish between normal and generated traffic, or at least that one can estimate it, say, 20 years after the opening of any new or improved highway facility. I believe that there is a clear definition of generated traffic for the first or the twentieth year after opening the new facility. It is, as nearly every transportation engineer has been taught to believe, the traffic generated by person trips, or goods movements that would not have taken place in the absence of the new facility. Where alternative facilities are being compared, then, it is the traffic that is generated by the superior utility or transport cost savings of the (usually) more expensive solution (the "with" case) that would not appear in the "without" case. There are, of course, many difficulties associated with forecasting the volume of this traffic, but that is outside the scope of the paper.

Winfrey has not given a convincing reason why one should ascribe to all traffic, normal and generated alike, the same level of benefits. It is, of course, a pragmatic way of getting an answer, and, in most cases, it will not seriously misrepresent the relative economy of 2 competing projects. Where the total travel engendered by competing projects is very different or the timing of a single proposal is being analyzed, then there could be substantial misrepresentation of relative economies. Embellishing Figure 2 of the paper somewhat we get Figure 5.

What Winfrey proposes is to equate the area (hatched area in Figure 2) between the 2 demand curves above the line BD with the area ADBE. Although in some cases this may not distort very much the relative economy of projects because the hatched areas are small in relation to total benefits or because they happen to be nearly equal, there seems to be no theoretical reason why the 2 areas should be approximately the same size.

Now let us come back to the first problem, the difficulties of applying the consumer surplus theory to the quantification of benefits and informing for decision making. Winfrey's postulation of a changed demand curve caused by improvements in the utility of travel other than cost savings is very useful in highlighting the difficulties inherent in the estimation of benefits and the definition of demand curves. It is true that there is a different demand curve for each hour of the day and variations of the curve with the season of the year. These can, however, be summed to give a demand curve for annual average daily traffic. Similarly, the demand curve shifts with time (normal traffic increases) so that we have a fresh basis for calculation each year derived from traffic forecasts.

The best theoretical solution seems to lie in efforts to quantify the "unquantifiable" whether it be the misery caused by a road accident or the disutility of noise to residents near a busy airport. Insofar as this can be done we can relate the 2 demand curves D_0D_0 and D_1D_1 and hence fix them at least for 2 points on each curve because the difference in the ordinates for a given value of Q_1 is the value of Q_1 of the improvement in utility from all the previously unquantified sources. Alternatively, one can, though theoretically it may be rather less rigorous, regard these extra benefits as reductions in costs and keep only 1 demand curve; this would be correct only if D_0D_0 and D_1D_1 differed by an ordinate of constant magnitude. When we consider the implication of such a requirement for simplifying the model, however, it should not be too unacceptable because, although people may vary in their valuation of safety, convenience, and the like, we always are dealing with statistical averages in our analyses so that we will, in effect, value each person's noncash benefits at the average figure for the whole involved population. Coming back to Figure 5, then, we can postulate a price P_2 that is P_1 less the cash valuation of noncash benefits. We now are back to the classical uncomplicated picture similar to Figure 1.

Although Figure 1 may be uncomplicated, the actual estimation of the value of noncash benefits is difficult and controversial. A common approach is valuation of the perceived costs that people are prepared to pay for increased utility (such as parking near the office) or to avoid loss of utility (such as traveling by bus rather than by car). Possibly the only, or main, category of cost that yields unsatisfactory values from this approach is the valuation of accident costs because people seem to be prepared, individually, to pay very little to reduce the likelihood of injury or death in an accident, but this pertains more to the application of the consumer surplus concept than it does to the theory itself. At any rate, the valuation of noncash benefits is difficult and can often involve contentious assumptions.

My conclusions, which differ from those of Winfrey, are as follows:

1. Consumer surplus theory is difficult to apply in highway transport economy, but, nevertheless, it is valid.

2. Application of the consumer surplus theory requires valuation of noncash benefits in cash terms whenever possible.

AUTHOR'S CLOSURE

The comments by Spottiswoode are well chosen and appreciated. They also agree with many comments I have received from economists. My major factor in rebuttal is that I am in no way trying to measure change in consumer surplus. I mean to calculate the changes in transportation costs that are priceable on the market because it is a preferred measure of the transportation economy. I reject the consumer surplus unit of measurement because it is a personal value concept, and I wish to quantify the changes by the reduction in consumption of resources for the same equivalent amount of transportation. Furthermore, if one is to adopt the consumer surplus measure of change, one must measure the total change in consumer surplus, including the change above the P_0 price level as well as that between the P_0 and P_1 price levels, for all route segments that experience change in traffic volume or cost per trip.

When one looks at Figure 1, the whole concept of consumer surplus is greatly simplified. An examination of Figure 3 injects many complications. The consumer surplus change wanted is that due solely to the change in price from P_0 to any higher or lower cost per trip. This total change must be estimated for a total geographic area that is affected by the improvement under consideration. There are increases and decreases in both P and Q on segments of the road network. You can have generated traffic on a segment that experiences a net decrease in total ADT. The forecaster takes all factors into consideration that relate to traffic. This includes land use changes far and near. An estimate of traffic with and without the proposed improvement includes a composite of changes of such complexity that generated traffic caused solely by the change in the market price level of a trip is not identified.

I am not trying to ascribe gross benefits at all. I merely am trying to determine the change in consumption of resources, or the economy of the transportation with and without the proposed investment. There is nothing in my paper that says I am equating the hatched areas mentioned by Spottiswoode. My claim is that the 2 price-demand curves cannot be established for want of quantification of Q trips at a range of values of P. What is wrong with this procedure?

I agree that the price-demand curve should be drawn on a basis of averaging out daily changes and even monthly changes. But, on the other hand, my reference to these changes is to point out that the price-demand curve continually changes and that even to draw any curve without knowing more about the price relationships than we now know is rather hopeless. When the highway users at peak hours are paying a higher cost per trip and are making more trips, they are certainly on a different price-demand curve than they were on at low hourly traffic volumes. And some changes in network travel come under conditions of increased P unit cost.

The discussion offered by Spottiswoode on quantifying the unquantifiable pertains to the user factors that are not quantifiable and are not priceable on the market. Such factors are not included in my calculation of the economy of transportation. But they do affect the user's choice of route and the location and shape of the unknown price-demand curve. As stated in my paper (this point, however, was not in the version available to Spottiswoode) in the analysis for transportation economy, the analyst is forced to use cost of trips based on market prices of vehicle use, traffic accidents, and value of time, none of which makes any allowance for outside values of the personal preferences of the road users. Therefore, the analyst cannot include in his or her calculation the added value that the drivers may attach to nonmarket factors.

Perhaps I am not well versed in the consumer surplus concept and price-demand curves, but I cannot see how 2 points can be established to enable a curve to be drawn between the 2 price levels. On the basis of market pricing of user costs, point A on curve D_0 and point B on curve D_1 are the only points that can be calculated and they are on separate curves.

The discussion by Carstens and Kannel is realistic; it is the best I have received in the many private conversations and discussions that I have had on the subject in the last 2 years when and where I have informally presented my views. But here, again, Carstens and Kannel neglect some factors.

I appreciate that Carstens and Kannel acknowledge that, in most ordinary analyses of the economy of transportation alternatives, the consumer surplus need not be computed (even if it could be done).

My concept and approach related to the penetration road in a developing country again has no reference to consumer surplus. First, consumer surplus cannot be established because of lack of price-demand curves, and, second, consumer surplus is not the determining factor on which to make the decision to build or not to build. There are just 2 factors of consequence (not considering the foreign trade balance, the shifting of population, and social aspects of the project if it were constructed).

First, the economic evaluation of the penetration road depends on the development of economic production, either by bringing new land into production or by harvesting local natural resources. The cost of the penetration road must be charged along with other economic costs to the harvesting of the new production and not as an improvement in transportation. The economic value of the new production is its value on the market less its cost to produce including the cost of the penetration road. The cost of the railroad to the iron ore deposits in western Australia is chargeable to the cost of harvesting the iron ore in the same way as the cost of the mining operation itself. This controversial subject, now that it is made public for the first time, should be discussed by both engineers and economists so that we will be better informed and perhaps agree on a procedure in cost-benefit analyses that gives acceptable results with reasonable effort. But I would like to know why others claim that the consumer surplus approach is better than my economy of transportation approach. So far, no one has informed me why the decision maker should prefer the evaluation of the change in consumer surplus to my quantification of the economy of transportation.

Second, the economy of road design, or project formulation, must be analyzed. The penetration road, assuming that it is economically justified on the basis of the market value of the production from the land, must be designed for the expected traffic loading in the same way that all engineering designs are formulated. That is, one must design the system for the lowest total cost over time and see that it adequately provides the safety level and quality of transportation desired. This step in no way depends on consumer surplus or the economic productivity gained as a result of the penetration road. It is simply a straightforward engineering process based on economy of design. It is the same as the process that a structural engineer uses to try out several locations and geometric shapes and materials for a bridge across a stream.

I should like to have economists and the doubting engineers study the Winfrey approach with the view that perhaps it is acceptable, rather than have them try to prove it is wrong. Except for Carsten and Kannel, many commentators have used the latter approach and have arrived at a negative conclusion without endeavoring to determine whether the approach will give acceptable and usable answers to the decision maker. My proposal does not encompass all the consequences that result from a highway improvement, but only that directly affecting the cost of transportation that can be market priced. All other factors are handled separately by whatever device is chosen by the decision maker in a separate report.

When I first came in contact with the consumer surplus concept, I accepted its logic and its application. But, after several experiences and much study, I concluded that the consumer surplus concept cannot and should not be used in analyzing the economy of transportation as applied to proposed highway improvements.

In the decision-making process, why is the measure of transportation economy proposed in this paper not an acceptable procedure? If it is not acceptable to the decision maker, why is it not? If it is not, why is the consumer surplus calculation, even if it could be calculated for the highway network affected, to be preferred?

CURRENT HIGHWAY USER ECONOMIC ANALYSIS

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This paper describes the result of a survey made of the current state highway user economic analyses. The survey was made in conjunction with the researchers' work on National Cooperative Highway Research Program Project 2-12, Highway User Economic Analysis, the objective of which is to produce a revised version of the 1960 AASHO Informational Report by Committee on Planning and Design Policies on Road User Benefit Analyses for Highway Improvements (Red Book). From the survey, it is estimated that 50 to 70 percent of the states currently perform highway economic analyses on a fairly regular basis. The results of the survey include information regarding types of applications of highway economic analyses; scope of such studies, amount of effort expended on them, and backgrounds of persons performing them; and types of data collected and values used in calculations. The paper concludes with a summary of suggestions derived from the questionnaire of what should be included in the revised Red Book.

•STANFORD Research Institute (SRI) is revising the 1960 AASHO Red Book (1) for the National Cooperative Highway Research Program (2). The purpose of the Red Book is to aid highway engineers and transportation planners in evaluating highway improvements for user operating costs, travel time, and accident experience. For example, an agency that wished to straighten out a curved section of highway could use the manual to compare its construction costs to highway users' savings in operating costs, travel time, and accidents.

To produce a document of maximum utility, the researchers distributed a questionnaire to all state highway departments on the status of their highway economy studies. We believe that the results of the questionnaire, which we present in this paper, in addition to assisting us in producing the revised Red Book (1) are of general interest to those in the highway community. They also provide feedback to transportation economists on current applications of economics in evaluating highway improvements in the real world. This paper also compares the answers from the states that participated in the survey.

This survey has been done twice before. The first survey (3), performed in 1962, revealed that, in almost 40 percent of the cases reported, economic analysis was never used; in those states that did use economic analysis, errors such as applying too low a discount rate, not including accident costs, not including maintenance costs, calculating road user benefits incorrectly, and not comparing alternatives correctly were prevalent. Unfortunately, many of these same criticisms still hold true today. The second survey (2) showed some increase in the number of agencies making economic evaluations of potential investments, but, very frequently, they used inappropriate or inadequate methods.

In this survey, started in May 1974, a 5-page questionnaire was sent to either the chief highway engineer, his deputy, the director of planning, programming, or budgeting, or to personal contacts, when available, in all of the 50 states plus the District of Columbia, Puerto Rico, and Guam. In this paper, these 3 territories will be called states. A copy of the questionnaire is an appendix to this paper[1]. The addressee was requested to have the proper individual prepare a response and to tell us the name and address of this individual. Forty responses were received; the last came in 4 months after the questionnaire was sent out. Thirty-five replies included completed questionnaires; this was a 66 percent rate of return. The 1962 study (3) received 50 replies to the 52 questionnaires sent out, which was a 96 percent rate of return. The 1966 survey (4) received 21 replies from the 47 states questioned, which was a 45 percent rate of return. We followed up on only 2 of the states from which we received no answer, and 1 replied. We followed up on no more because we felt that we had received a sufficient number of returns. Some of the states, in addition to returning the questionnaire, included copies of highway user economic evaluations that they had performed previously. These reports have given us as much useful data as has the questionnaire itself, and we plan to include some of them in the revised Red Book (1) as examples. A few of the states (most notably California and Oregon) gave us copies of highway user economy analysis manuals that they prepared for their own use. These also have proved to be valuable to our research.

Highway user economy studies are conducted by 27 states out of 39 replying (69 percent); 8 states conduct limited studies. Only 1 state responding to our survey does not perform this type of analysis; 3 others conduct them only rarely or would like to start performing this type of analysis soon. We assumed that a large fraction of those states that did not respond to our survey do not perform highway economy studies. Thus we estimate that from 50 to 70 percent of the states perform these analyses on a more or less regular basis. This is 10 to 20 percentage points higher than the results of the 1962 questionnaire (3).

The second question asked at what point in the transportation planning process these analyses occur. Seven states said that they are performed at the initial highway feasibility stage; 12 states said that they are performed during prelocation corridor planning; and 20 states said that they are performed during alternate route location selection. Of course, some of these states conduct analyses at 2 or 3 of these points. Six states report performing an economic analysis for design or pavement selection. Three to 5 states indicated that they conducted road user benefit analyses in the statewide or systems planning stage in conjunction with preparing environmental impact statements for highway maintenance, during reconstruction or rehabilitation, or when requested by upper management.

The third question asked whether economic analyses were used for solving the types of problems given in Table 1. A weighting similar to that used by Glancy (3) was employed: Yes = 1.0; qualified yes = 0.75; qualified no = 0.25; and no = 0. It is interesting that interchange justification was a write-in by the 5 states who indicated it; we had not included it on the questionnaire form. If we had included it, more states probably would have indicated the use of highway economic analysis for justification of freeway interchange location and spacing.

The median number of person days required for a typical economic analysis was 5 to 10. The range was from 3 person hours to 15 person days or more. Seven states indicated that they would like their analyses to take approximately half as long to perform as they do now.

Twenty-four states would prefer to have a highway user economic analysis methodology that is as simple as possible as long as it is reasonably accurate. Nine states, however, would like to have the capability to perform a more detailed analysis, especially one that could be run on a computer.

The number of highway economy analyses performed per year by the states varies widely. Two states perform only 2 such analyses per year. Two other states, however, can do up to 2,000 per year. The median is 18 user benefit analyses per year.

[1] The original manuscript of this paper included an appendix, Questionnaire on the Conduct of Highway Economy Studies. The appendix is available in Xerox form at cost of reproduction and handling from the Transportation Research Board. When ordering, refer to XS-59, Transportation Research Record 550.

Table 1. Weighted percentage of states performing economic analyses.

Type of Highway Problem	States Replying	
	1974 (N=35)	1962 (N=50)
Construction of new highways	71	82
Deciding among alternative routes	87	92
Road surface selection	19	70
Safety improvements	44	82
Widening existing roads	36	Not reported
Straightening curves	31	Not reported
Grade reductions or passing lanes on mountainous roads	39	Not reported
Interchange justification[a]	14	2
Other, e.g., rehabilitation, drainage, routing of detours, and grade separation	14	Not reported

[a]Write-in response; actual use is probably higher than that shown.

Table 2. Who conducts the analyses.

Analyzers	Experience	Number of States
Highway engineers	Experienced	14
	Relatively inexperienced	5
	Unspecified	3
Civil engineers	Experienced	11
	Relatively inexperienced	3
	Unspecified	1
Design engineers	Experienced	2
	Relatively inexperienced	1
	Unspecified	2
Economists	Experienced	6
	Relatively inexperienced	2
	Unspecified	1
Planners	Experienced	9
	Relatively inexperienced	5
	Unspecified	4
Technicians and others		9

Table 3. Values for capital costs, accidents, and time.

Variable	Number of States Responding	Median Value
Discount rate (cost of capital)	24	7 percent/year
Social cost of fatalities	20	$52,000/fatality
Societal cost of injuries	20	$2,700/injury
Amount of property damage	7[a]	$415/property-damage-only incident
Value of time for each passenger car occupant	16	$1.85/hr

[a]Write-in response.

Our next series of questions attempted to find out something about the individuals who conduct road user benefit analysis. Their backgrounds can be described by the data given in Table 2. The category of technicians and others includes people who might be described as research assistants, accident analysts, or traffic specialists. Many technicians perform highway user economy studies regularly and are quite skilled in performing the calculations even though they may not fully understand the underlying theory.

In most states, the fraction of time spent by individuals performing these analyses is small. The median value is 8 percent. The activities with which they usually concern themselves are as follows:

Responsibility	Number of Agencies
Engineering	12
Planning	13
Traffic Analysis	10
Design	7
Research	7
Highway investment programming	2
Environmental assessment	5

We then asked what type of computing equipment is available for these analyses. Twenty-six states have computers available for performing the calculations (13 of these computers are IBM 370s), and 5 of these use their computers for this. Oregon has a highway investment rate of return program, and California is refining a sophisticated highway economic evaluation program model. Fourteen states use electronic calculators in performing the calculations, and 2 others have calculators (including a calculator that can be programmed) available for use. Eight states perform manual (paper, pencil, and slide-rule) computations.

The next series of questions concerned the type of field data that is collected by the states for performing the evaluations. The following tabulation describes the data collected by the states:

Type of Field Data	Number of Agencies
Traffic volumes	23
Speed	8
Geometrics	12
Vehicle categories, percentage of trucks	6
Accident experience	6
Costs	9
Trip origin-destination	8
Other	7

The category of other includes data on type of pavement, pavement condition, service life, traffic control, land use, and socioeconomics.

Next we asked which reference books are used to assist the states in performing their road user benefit analyses. Twenty-five states still refer to the 1960 Red Book, and 13 of these still use the original 1959 unit price values in the book. They realize, of course, that these numbers have been rendered obsolete by inflation and technological changes, but they use them nevertheless. In fact, they requested that we produce in our revised methodology a technique that would enable them to justify highways on a cost basis because the values that they have for construction have been inflated greatly since 1959. Some of the other 12 states use the format in calculations in the Red Book and merely update the cost values. Five states use NCHRP Report 111 (5), and 7 use NCHRP Report 133 (6). Fourteen states use Robley Winfrey's Economic Analysis for Highways (7), and 7 states use other references such as NCHRP Report 122 (8), manuals that have been prepared by the state, and books by Woods and Wiener.

The next question requested information on the actual values that the states assume for the costs of capital, accidents, and time. The results are given in Table 3. It is significant that 25 states (71 percent) reported that they use a non-0 discount rate. The comparable value for the 1962 survey was only 55 percent. High interest rates notwithstanding, several state highway departments have become aware of the time value of money in the last 10 years. There has been a tremendous increase in the inclusion of accident costs in an economic analysis. In the 1962 study (3), only 2 states considered accident costs, and only 4 states included them in the 1966 survey (4). Twenty-one states in our sample reported the inclusion of accident costs in their analyses.

The next question concerned the actual effectiveness measure that is used in analysis. Thirty-two states perform cost-benefit analysis. Twenty-four of these compute benefit-cost ratios. One uses a marginal benefit-cost ratio, and a few include maintenance costs in either the numerator or the denominator. Eight states used other indicators, such as net present worth, net benefit, a comparison of total or annual system costs, and rate of return.

The final questions were on the recommendations that the states made concerning NCHRP Project 2-12 (2). These are given in outline form.

1. Suggestions for incorporation into revised Red Book
   a. Include a discussion of net present worth, net worth of costs, rates of return, and the like that can be understood by those not well versed in economics and can be presented to the uninitiated general public.
   b. Provide a sensitivity analysis to illustrate the relative importance of the various components of highway user costs and show the sensitivity of the final answer to assumed values for time and interest rates.
   c. Include a detailed working of simple to complex sample problems, including some with incomplete data.
   d. Show the effect of air-pollution-control devices on highway user costs.
   e. Indicate highway user costs for different levels of service and types of roads. When representing running costs as a function of speed, start with a lower operating speed than that used in the Red Book and use 5- or 10-mph (8- or 16-km/h) increments rather than 4-mph (6-km/h) increments that are used now in the Red Book.
   f. Express speed change cycles as a function of congestion levels
2. Comments on manual format
   a. Use larger pages than are used in the present Red Book.
   b. Tables, charts, and graphs should be easily reproducible.
3. Requests for work beyond scope of NCHRP Project 2-12
   a. Include a treatment of social, economic, environmental, and community impacts in addition to user costs.
   b. The computer programs that are being used for comprehensive transportation and traffic forecasting should be extended to calculate user costs.
4. General comments
   a. Include a discussion of motor vehicle costs in urban areas, and use average daily traffic instead of hourly traffic in the calculations.
   b. Develop an economic methodology and updating procedure that is simple to apply; develop also a rough, shortcut approach for feasibility determination.
   c. Make the procedure flexible and interchangeable so that it can be used for many different applications.
5. Suggestions for further research
   a. Discuss deterioration in performance due to vehicle age.
   b. Include the costs for different classes of vehicles, such as trucks and recreational vehicles.
   c. Devise an accurate method for estimating speed and determine the effects of buses and trucks in the traffic stream on average speed now that national speed limits are lower.
   d. Model queuing due to bottlenecks.
   e. Derive a methodology for treating accidents and delay for interchanges, intersection improvements, auxiliary lanes, ramp metering, and the like.

We have found that many of these suggestions will be valuable to us in revising the Red Book.

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INVESTMENT EVALUATION MODEL FOR MULTIMODAL TRANSPORT CORRIDORS

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A method of economic evaluation of centrally focused multimodal urban transport corridors is presented that is based on certain production theory principles. Production functions are developed in terms of average door-to-door travel velocity in a corridor as a function of commuter-rail and expressway-facility inputs. Cost data are used to establish the optimum combinations of transport mode inputs for various travel speeds. The information used to develop the relationships was obtained in the Toronto region. The use of the techniques described in the paper allows the technical and economic characteristics of the modes to be examined in a quasi-continuous way, which allows a broad range of potential modal combinations to be evaluated. This is in contrast to the normal economic evaluation approach, which chooses from among a set of mutually exclusive, mode-specific alternatives that may not include the optimal alternative. The framework allows the examination of a range of policy variables such as parking charge changes in the central business district and the effect of dial-a-bus as a residential feeder mode.

•MUCH has been written in transport planning literature about the need for urban transport systems that have a balance between public transport and highway-oriented systems. However, an evaluation technique does not exist that allows this notion of balance to be identified objectively. A variety of urban transport economic evaluation techniques have been directed toward the evaluation of single-mode, mutually exclusive, transport-investment projects (1, 2, 3).

In most medium-to-large urban areas, travel within transport corridors is provided by a mixture of complementary transport modes. Rahman and Davidson (4) have proposed a technique for evaluating a transport system consisting of road and bus transit facilities, and they have applied this technique in a general way to transport investment evaluation in Brisbane, Australia. This technique is based on certain principles of the theory of production of microeconomic theory. There are difficulties with the way in which urban transport as a productive process has been conceptualized by Rahman and Davidson (4).

This paper describes a method of economic evaluation for multimodal transport corridors that also is based on the theory of production. The method of evaluation advanced in this paper is illustrated by a slightly idealized example of a typical radial transport corridor within the Toronto region.

URBAN TRANSPORT CORRIDOR

Figure 1 shows an idealized urban transport corridor that is typical of certain radial corridors within the Toronto region. In the corridor illustrated, 2 suburban areas are

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located 15 and 25 miles (24 and 40 km) from the central business district along a radial corridor. These 2 communities are to be connected to the central business district by some combination of road and public transport facilities.

Table 1 gives data on the commuter travel demands expected along this corridor throughout the day. The peak-hour demand from each community is 6,000 trips, and it is assumed that 5 peak hours are in each day, which yields 30,000 peak-period trips from each community. It is assumed as well that there are 30,000 off-peak-period trips per day, which yields a total daily person-trip demand of 120,000 trips.

The corridor characteristics presented in Figure 1 and Table 1 are similar to the characteristics of corridors in the Toronto region within which commuter-rail services have been established or are contemplated. Actual demand characteristics have been idealized, and the number of communities served has been reduced to 2.

In the example discussed in this paper, the only 2 modes of transport considered for the corridor are a commuter-rail facility and an expressway. Bus transit options have been analyzed by using the techniques discussed in this paper, but these options are discussed elsewhere (5).

Certain assumptions were made in the analysis described in this paper.

1. No existing expressway or commuter-rail facilities are in the corridor.
2. The facilities will be located equally in urban and rural areas where land market prices are \$50,000 and \$2,000/acre (\$125,000 and \$5,000/hm^2) respectively; all other costs are in 1969 prices.
3. The discount rate is 8 percent/year.
4. All trains in the peak hour have 10 coaches.

TRANSPORT MODE COST FUNCTIONS

Total annual costs for several transport modes have been calculated by using typical cost data for the Toronto region (5). The input quantities of the 2 transport modes were characterized by the following units:

1. Number of expressway lanes in 1 direction for highway facilities and
2. Number of trains per hour in 1 direction for commuter-rail facilities.

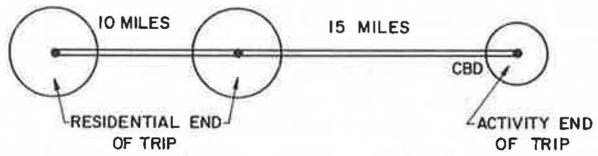
Costs included in the transport mode cost functions were costs associated with providing the corridor facilities and services (agency resource costs) and nonperceived costs of using the facilities and services for automobiles. Several or all of the following cost components, depending on the mode analyzed, were included in the agency resource cost element of the total cost function:

1. Land acquisition,
2. Traveled way and structures,
3. Rolling stock,
4. Parking facilities,
5. Maintenance,
6. Operation, and
7. Overhead and administration.

The second element included in the total cost function is nonperceived user cost of automobile operation. Half of these annual costs were assigned to corridor trip making and were divided by 1.3 to account for an estimated car occupancy rate. The components of these nonperceived user costs are capital and fixed costs of car ownership and nonmarginal costs of car operation.

A detailed description of the derivation of the transport mode cost functions is presented elsewhere (5). Tables 2, 3, and 4 give a summary of the total annual costs per mile (kilometer) of the various types of transport facilities analyzed. Figures 2 and 3 show a summary of cost functions for automobile and commuter-rail modes as

Figure 1. Radial transport corridor characteristics.



Note: 1 mile = 1.6 km.

Table 1. Summary of corridor demand characteristics.

Time Period	Number of Person Trips, All Purposes		
	Community A CBD	Community B CBD	Total
Peak hour	6,000	6,000	12,000
Peak period[a]	30,000	30,000	60,000
Off peak	30,000	30,000	60,000
Daily[b]	60,000	60,000	120,000

[a]Assuming 5 peak hours in a day.
[b]Total daily trips = 10 times the number of peak-hour trips. Daily peak-period trips/daily non-peak-period trips = 1.0.

Table 2. Total annual automobile costs per mile (kilometer).

Lanes in 1 Direction	Costs (dollars)	Lanes in 1 Direction	Costs (dollars)
2	309,000	7	496,000
3	340,000	8	523,000
4	369,000	9	541,000
5	399,000	10	577,000
6	471,000		

Note: $1/mile = $0.62/km.

Table 3. Total annual bus costs per mile (kilometer).

Buses per Hour in 1 Direction	Costs (dollars)		
	Busway	Exclusive Lane	Mixed Traffic
20	193,000	93,000	27,000
40	200,000	100,000	37,000
80	215,000	115,000	56,000
120	231,000	132,000	78,000
160	246,000	146,000	97,000
200	261,000	161,000	117,000
240	277,000	178,000	137,000
320	308,000	208,000	178,000
400	346,000	248,000	226,000

Note: $1/mile = $0.62/km.

Table 4. Total annual rail costs per mile (kilometer).

Trains per Hour in 1 Direction	Costs (dollars)	Trains per Hour in 1 Direction	Costs (dollars)
2	223,000	12	432,000
4	258,000	14	453,000
6	306,000	16	476,000
8	339,000	18	540,000
10	401,000	20	558,000

Note: $1/mile = $0.62/km.

Figure 2. Facility cost functions for commuter-rail facilities.

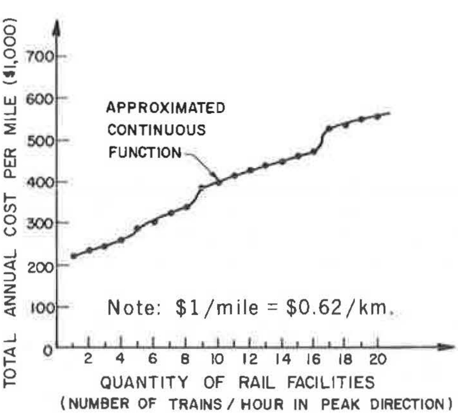
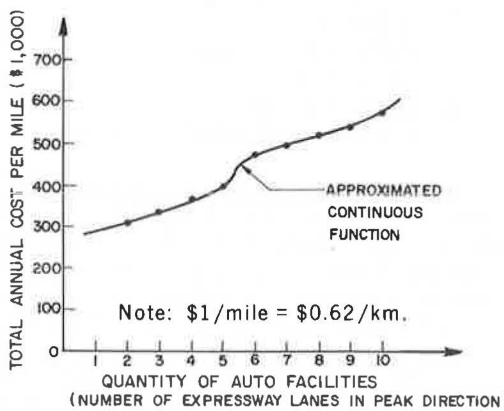


Figure 3. Facility cost functions for automobile facilities.



continuous functions. These functions are, in reality, step functions.

TRANSPORT MODE ISOCOST CURVES

Table 5 gives the combinations of automobile and commuter-rail facilities that can be supplied for $800, 000 per year. Similar isocost tables could be constructed for other equivalent annual investments. Figure 4 shows the family of isocost curves developed for the corridor shown in Figure 1. The irregularities in these isocost curves are a reflection of the discreteness of transport investment. The isocost curves are shown as continuous functions in Figure 4 even though feasible combinations of the 2 transport modes exist only at a specific number of supply conditions.

Although the cost functions shown in Figure 4 are not linear, the average unit cost of the expressway facilities is about $33,000/lane/mile ($20,500/lane/km). The average unit cost of the commuter-rail facilities is about $18,000/train/hr/mile ($11,200/train/h/km).

TRANSPORT CORRIDOR PRODUCTION ISOQUANTS

Transport corridors function by combining the capabilities of various transport modes to provide transport service for the demand expected in the corridor. Various combinations of transport modes may be used in a corridor to produce various levels of transport service. This process of producing transport service in a corridor may be described in terms of an economic concept called a production isoquant. A production isoquant is simply a function showing all combinations of inputs technically capable of producing a given level of output.

The level of transport service provided in the corridor has been described in terms of the average speed of travel of all users within the corridor. Thus the transport production isoquants are described in terms of various average travel speeds. Figure 5 shows the sequence of activities followed to establish the production isoquants.

Points on the production isoquant graph are obtained by postulating a specific combination of transport modes and then calculating the average speed of travel in the corridor. An initial estimate of the modal split in the corridor was made, and the transport demand given in Table 1 was allocated between the 2 modes. The user-perceived travel costs for each transport mode were estimated by using the generalized travel cost concept. These line-haul costs then were added to the costs incurred at the residential and employment ends of the trips. Table 6 gives the generalized travel cost formulas used.

Figure 5 shows that a 2-stage modal-split model was used to allocate the travel demands between the modes. A constant number of captive transit riders were identified and a logit-modal-split model that uses generalized travel cost differences was used to estimate the split of choice riders. The modal split estimated initially was then compared with the calculated modal split, and the process was reiterated until a stable modal split was obtained. This iterative sequence is necessary because travel time on each mode is a function of the patronage of that mode. Calculation of the equilibrium modal-split proportion then allows average corridor velocity of all trip makers to be estimated, and this provides 1 point on the production isoquant.

Figure 6 shows the isoquant curves developed for the commuter-rail and freeway corridor for a range of average corridor travel speeds from 23 to 50 mph (37 to 80 km/h). The points calculated by the analysis sequence shown in Figure 5 are shown in Figure 6.

For a specific average speed, a production isoquant in Figure 6 shows the marginal rate of substitution of rail facilities for road facilities. The isoquants shown in Figure 6 indicate that, as the input of each mode increases, the marginal productivities of the modes decrease. The initial increases in the supply of either mode produce larger increases in the average corridor velocity than subsequent increases do.

Table 5. Mode combinations obtainable with $800,000 annual investment.

Freeway Lanes	Annual Investment (dollars)		Trains per Hour
	Automobile	Rail	
2	309,000	491,000	16
3	340,000	460,000	14
4	369,000	431,000	11
5	399,000	401,000	10
6	471,000	329,000	7
7	496,000	304,000	5
8	523,000	277,000	4
9	541,000	259,000	4
10	577,000	223,000	1

Table 6. Generalized travel cost formulas.

Mode	Trip Distance (miles)	Cost Plus Time Formula (dollars)
Automobile	15	$1.85 + 0.02^{a}$
Automobile	25	$2.16 + 0.02^{a}$
Rail	15	$1.68 + 0.02^{a} + \frac{0.05^{b}}{2}$
Rail	25	$2.13 + 0.02^{a} + \frac{0.05^{b}}{2}$

Note: 1 mile = 1.6 km.

[a] Correction time factor. [b] Rail headway factor.

Figure 4. Isocost curves for a rail-automobile corridor.

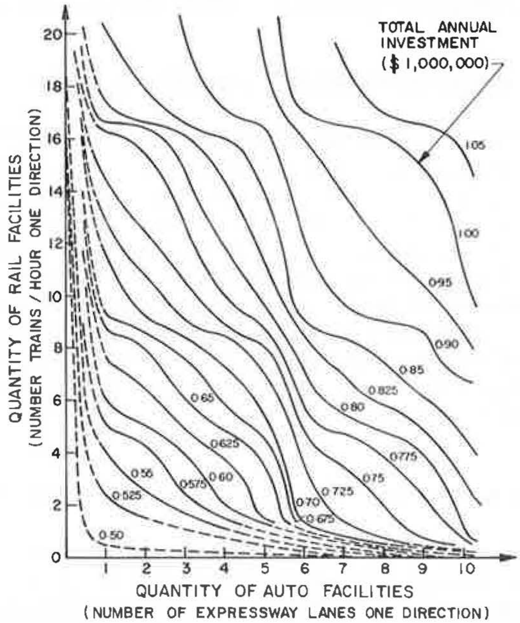
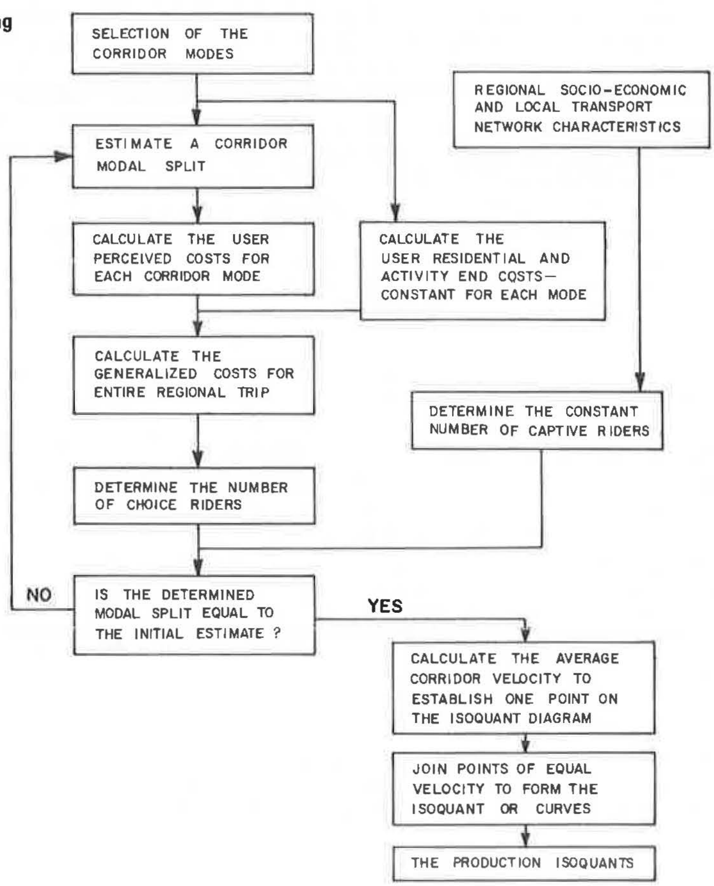


Figure 5. Process for calculating isoquant functions.



Figures 7 and 8 show the change in marginal productivity of both modes for 2 levels of input. These figures demonstrate clearly the decreasing marginal productivities of the 2 modes. In 1 case shown in Figure 7, there is an initial increase in the marginal productivity of the commuter-rail service. This figure also demonstrates that the marginal productivity of the modes is smaller when the supply of the second mode is higher, which is not an unexpected result. For example, unit changes in the number of commuter-rail trains per hour are much more effective when only 3 expressway lanes are supplied than when 4 expressway lanes are supplied. Similar comments may be made about the marginal productivities of the expressway lanes, which are shown in Figure 8.

The slope of the transport corridor isoquant curves is a reflection of the technological characteristics of the 2 transport modes and the modal-split behavior of passengers. For the commuter-rail mode, the initial increments in the level of train service (up to the point at which supplied seat capacity equals seat demand) serve to relieve highway congestion and shorten train headways. Therefore, marginal productivities increase. When 5 trains run per hour and 3 expressway lanes are supplied, unit increases in the train level of service will only decrease the train headways. Further increases in the rail service have a diminishing marginal effect on rail patronage because fewer people are diverted from the car mode. Furthermore, expressway speed is increased only slightly, and overall average corridor velocity is not increased substantially.

The important implication of the decreasing marginal productivity characteristics of transport modes is that simple relationships do not exist between input and output levels. For example, increasing the supply of 1 transport mode while keeping the supply of the second transport mode constant will have an important effect on average corridor velocities at some levels, but, at other supply levels of the second mode, it will have an insignificant effect.

The family of isoquant curves shown in Figure 6 demonstrates that decreasing returns to scale are evident for the modes in this corridor. Doubling transport facilities does not double average corridor velocity. Consequently, it may be expected that optimum corridor velocity would tend toward the lower range of speeds because user benefits are more or less a direct function of average velocity. In addition, because diminishing marginal productivities exist for both modes, one would suspect that optimum velocity would tend toward the central area of the diagram.

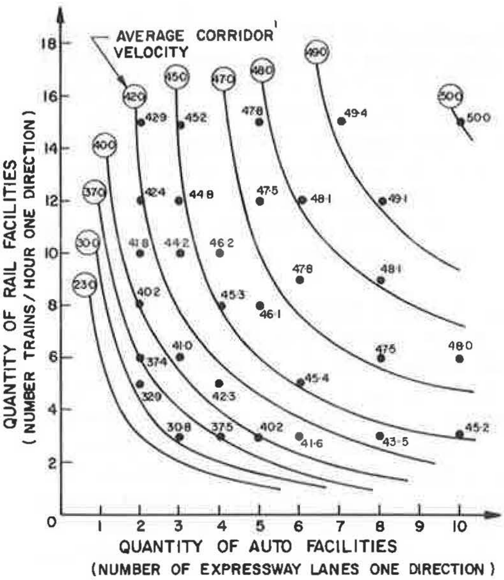
EQUILIBRIUM TRANSPORT MODE COMBINATIONS

Figure 9 shows the isocost curves of Figure 4 superimposed on the isoquants of Figure 6. For any average speed isoquant, the least cost combination of modes required to produce that speed is given by the point of tangency between the isoquant and the isocost curve immediately tangent to it. The solid dots in Figure 9 identify the least cost combinations of transport modes required to produce each of the average corridor travel speeds. These points do not necessarily represent technically feasible combinations of modes. The nearest feasible combinations of modes may be selected from the figure.

The expansion path also is shown in Figure 9. Below an average corridor speed of about 43 mph (69 km/h), the efficient transport mode combinations are located generally in the central region. That is, if transport investment is increased in the corridor, then it should be distributed in the same proportion between the modes. The expansion path indicates that, beyond about 43 mph (69 km/h), additional investment should be channeled into commuter-rail facilities. Beyond about 47 mph (76 km/h), the investment should be directed toward expressway facilities. Inspection of Figure 3 shows that expressway costs accelerate to supply 6 instead of 5 expressway lanes. However, as soon as the sixth lane has been added, increasing the number of expressway lanes becomes superior for a number of investment increments.

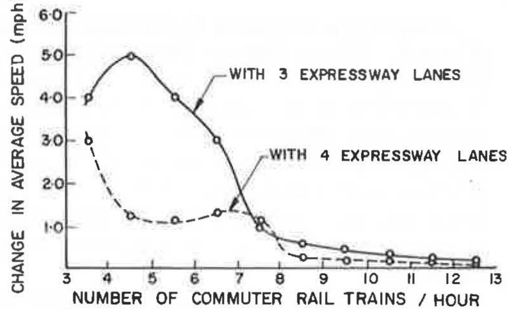
The expansion path is also a reflection of the choice- and captive-rider proportions in the corridor. Initial investments in the expressway increase the average speed of choice riders. However, after a certain level, investments in the commuter-rail ser-

Figure 6. Isoquant curves for a rail-automobile corridor.



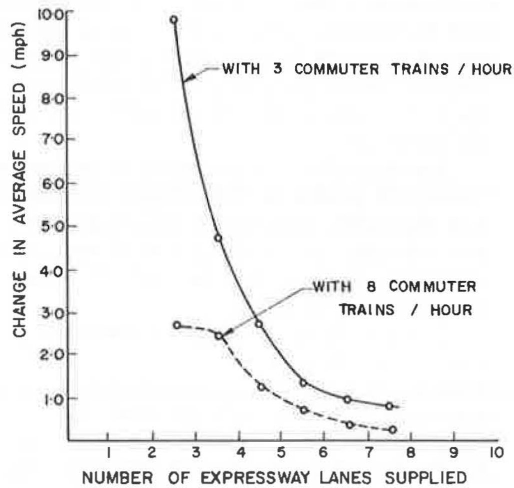
Note: 1mph = 1.6 km/h.

Figure 7. Marginal productivities of commuter-rail mode.



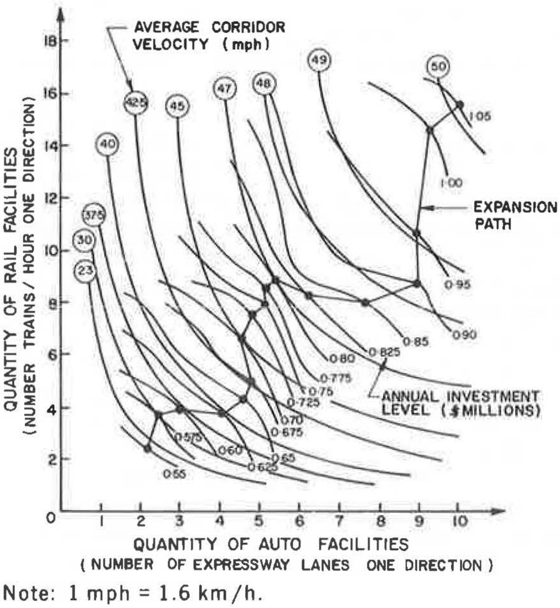
Note: 1 mph = 1.6 km/h.

Figure 8. Marginal productivities of automobile mode.



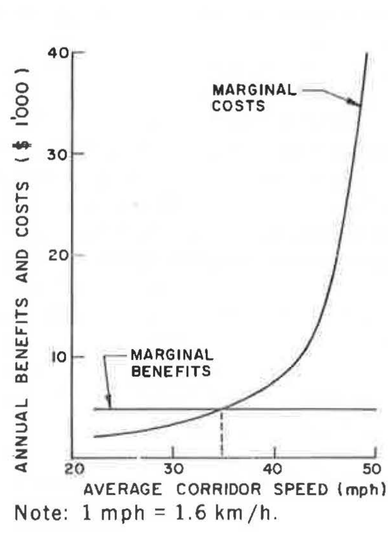
Note: 1 mph = 1.6 km/h.

Figure 9. Production diagram for a rail-automobile corridor.



Note: 1 mph = 1.6 km/h.

Figure 10. Marginal benefit and long-run marginal cost curve.



Note: 1 mph = 1.6 km/h.

vice are required before average corridor velocity will begin to increase again.

A principal advantage of displaying corridor travel characteristics in the manner used in Figure 9 is that the implications of various transport policy assumptions may be displayed easily. For example, it may be judged that the average deleterious effects of expressways are equivalent to an annual cost (for example, property value deterioration) of about $5,000/lane/mile ($3,100/lane/km). This unit cost may be added to the unit expressway costs. This would have the effect of rotating the isocost line so that it would have a larger negative slope. The points of equilibria then would involve use of more commuter-rail services and fewer expressway facilities.

Additional policy proposals that may be displayed readily on a diagram such as that shown in Figure 9 are the effects of downtown parking charge changes and dial-a-bus services as a feeder mode to commuter-rail stations. Both of these would influence the generalized travel costs and, therefore, the modal choice behavior of trip makers.

USER BENEFITS

Marginal user benefits between successive efficient combinations of facilities are changes in consumer surplus. In this case, because of the inelastic nature of the demand, the change in consumer surplus is equal to the change in generalized travel costs for all users. Figure 10 shows the marginal benefits and marginal costs per mile (kilometer) for the range of modal combinations identified in Figure 9.

Figure 10 shows that marginal benefits decrease rapidly at corridor velocities greater than 35 mph (56 km/h) and become fairly constant at about 44 mph (71 km/h). The optimum overall corridor velocity suggested by Figure 10 is about 35 mph (56 km/h). The nearest feasible combination of facilities produces an average corridor velocity of 36 mph (58 km/h).

At optimum velocity the annual investment cost is $600,000/mile ($370,000/km). Fifty-seven percent of the cost is to provide 3 expressway lanes in 1 direction, and 43 percent is to provide four 10-coach trains in the peak hour in the peak direction. The user cost is $371,000/mile/year ($230,000/km/year) for this condition.

ADVANTAGES OF EVALUATION METHOD

The approach to transport corridor mode evaluation described in this paper allows the economic properties of a range of alternatives to be displayed and examined in contrast to the usual project economic evaluation method. The project methodology allows the analyst to choose the best alternative from a set of mutually exclusive project alternatives. There is no guarantee, however, that the set of mutually exclusive alternatives examined includes the optimal alternative. The use of the theoretical concepts of production theory allows the analyst to display the performance and economic characteristics of the transport options in a given corridor in a quasi-continuous way. In this way the analyst may identify those regions of the production isoquant that isolate the optimal combinations of modes.

Another advantage of the approach described in this paper is that a large number of potential transport policy options for a corridor may be displayed easily and effectively. The shapes of the production isoquants are a function of the properties of the modes and the modal-split behavior of trip makers. Changes in parking charges or other non-line-haul components of the generalized cost of travel that influence modal choice may be analyzed, and changes in the production isoquants may be established. The new equilibrium positions for each alternative policy set then may be estimated.

CONCLUSIONS

This paper has demonstrated that certain concepts of production theory may be used to characterize the service properties of a bimodal corridor transport system. Transport production isoquants have been developed in terms of average door-to-door travel velocity and the amounts of input of commuter-rail and expressway facilities. Commuter-rail inputs have been expressed in terms of the number of 10-car trains/hr, and the expressway inputs have been expressed in terms of the number of expressway lanes in 1 direction.

The equivalent annual costs of various combinations of the 2 transport modes may be displayed in terms of isocost curves that allow isolation of least cost combinations of the transport modes for various average speeds. The expansion path shows the locus of least cost facility combinations and is an important concept for long-range facility planning. If it is planned to increase average speed in the corridor over time, then the facility requirement implications of such a policy may be examined easily.

The principal advantage of the approach described in this paper is its flexibility. A range of policy variables may be analyzed, and their effects may be displayed easily and effectively. In addition, nonuser effects on the equilibrium combinations of transport modes may be examined readily.

ACKNOWLEDGMENTS

The research described in this paper was conducted at the University of Waterloo under a grant made available by the National Research Council of Canada. The Ontario Ministry of Transportation and Communications and Peat, Marwick and Partners, Toronto, provided a number of publications from which information was extracted.

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BENEFIT-COST ANALYSIS OF THE MILWAUKEE FREEWAY SYSTEM

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This study analyzed the effects of freeways on property taxpayers in Milwaukee. Right-of-way takings for the Milwaukee freeway system resulted in the removal of real estate property from the city's tax base. Total tax loss was estimated to be more than $18 million. However, accident cost savings, savings in travel time and operating costs, and reduced capital expenses for arterial streets benefited city residents by more than $37 million. Figures also are given for individual property owners. The scope of the analysis was limited to the quantifiable items for which data were available. For some items, available data were not fully adequate and many assumptions had to be made. A conservative approach was taken to ensure that benefits were not overestimated. A direct effect of freeways excluded from the analysis is environmental impact. Indirect effects that were not considered include the impact of freeways on the land development pattern and land value, which may be significant in many cases. It was concluded that the Milwaukee property tax loss due to freeway right-of-way takings was compensated for amply by the benefits attributable to the freeways.

•IN RECENT years freeway construction in metropolitan areas has been the cause of much controversy and has been opposed by various groups of people for different reasons. Environmentalists oppose freeways because of their impact on the landscape, quality of air and water, and noise level. Other opponents, particularly property owners, are upset about the dislocation of business and families, and the effect of the freeway on adjacent neighborhoods. In addition, city government officials, particularly those of the central city, are concerned about the lost tax base of their cities. The study to be discussed in this paper analyzed the effects of freeways on property taxpayers within a municipal area by examining the case of Milwaukee, Wisconsin.

The study used the traditional benefit-cost approach, but included only those benefits and costs that are related directly to city property taxpayers. Because of the difficulty of precisely quantifying the benefits that accrue to city residents from a freeway system, some approximations were made in a few cases. The quantified benefits in this study basically represent savings in road-user costs. One item, however, is related to capital costs that accrue to the city. Cost, for this study, was the city's lost tax base. The study did not attempt to deal with any particular group of property owners who were displaced or who suffered a reduction in the value of their property because of a freeway. All types of real estate and improvements (residential, manufacturing, mercantile, and agricultural) were included in the analysis. Personal property assessments, however, were not included.

In addition to estimating areawide totals, we converted benefits and costs to a unit property value for an owner of a real estate property with a market value of $20,000, which approximated the median value of single-family homes in southeastern Wisconsin in 1970 (1). The objective of converting the total benefits and costs to a unit property basis was to provide information that would be more meaningful for individual residents and more helpful for comparisons.

All aspects of a freeway were not included in this study. The focus of the study was on the extent of tax loss suffered by the city because of the freeways. The study also focused on the magnitude of direct or indirect benefits that accrue to residents and road users by reduced accidents, travel time, and vehicle operating costs and to the city by lowered demand for additional surface arterials. The positive effects of a freeway system on increased mobility and higher land value were not quantified, and possible negative effects, such as air pollution, noise, and dislocation of neighborhoods, were not included in the analysis.

FREEWAY CONSTRUCTION AND THE TAX BASE

The assessed value of property removed from the tax base of the city of Milwaukee by right-of-way takings for freeways was obtained from the Milwaukee Tax Commissioner's Office. Only that portion of the freeway system within the corporate limits of the city that was operational by January 1, 1971, was considered. The monetary valuation in each year of the analysis was based on the value of the dollar in that year. For estimating annual tax, we adjusted the value of previously acquired properties on a year-to-year basis to reflect the likely appreciation of property value. These increases were based on consumer price indexes. (Price indexes for housing could have been substituted. The difference was not significant for Milwaukee.) They applied to all properties even though much of the existing freeway system in Milwaukee was constructed through marginal and substandard neighborhoods.

The assessed values of annual right-of-way takings for freeway construction in the city of Milwaukee for 1953 to 1970 are given in Table 1. Assessed value of real estate properties in Milwaukee for tax purposes is approximately 55 percent of the market value. The cumulative value of the real estate tax base removed for freeways was $26,316,486 for 1970 if individual annual values are not adjusted. No tax base was removed after 1967 because all land parcels were acquired before the end of 1967 for the freeway segments that were open to traffic on January 1, 1971. The table also indicates that, when inflation factors based on increases in the consumer price index (CPI) are applied, the cumulative value of the lost tax base increases to $33,064,860 for 1970. The adjusted cumulative values were used for estimating the city's lost real estate tax dollars.

For this study, it was assumed that the city's operating costs were not diminished although services were not provided to those properties removed from the tax rolls. Thus, to maintain the same level of revenue, the city had to redistribute the entire amount of lost tax among the remaining real estate taxpayers. The lost revenue for the years 1953 to 1970 is given in Table 2. The total loss amounted to $18,758,330. The lost tax dollars then were distributed over the entire city tax base, and a yearly cost in added taxes was determined for a property with a $20,000 market value. The market value of all real estate for the city and the derived cost for a property with a $20,000 market value also are given in Table 2. As shown by the data given in the table, the added property tax to the typical property owner would be $107.56 or an average annual cost of $5.98 for the 18-year period under investigation.

ACCIDENT COSTS—FREEWAYS VERSUS SURFACE STREETS

Much has been written on the accident reductions that result from the advanced design features of freeways across the nation, and, as revealed by this study, the accident cost savings in the Milwaukee area attributable to the freeway system were significant. In determining the accident rates for the city, we had to determine the total vehicle miles (kilometers) of travel (VMT) on Milwaukee streets. In 1963, total travel on the city's arterial street network during a typical weekday was estimated to be 4,804,000 vehicle miles (7 734 440 vehicle km) based on traffic counts and the length of roadway sections within Milwaukee corporate limits. The corresponding total daily travel on nonarterial streets was estimated to be 870,000 vehicle miles (1 400 700 vehicle km). Saturday and Sunday traffic was estimated to be 84.18 percent and 71.66 percent of

Table 1. Year-to-year values of freeway right-of-way takings for Milwaukee.

Year	Total Assessed Value (dollars)	Consumer Price Index Value (1957-1959 dollars)	Increase in Consumer Price Index Over Previous Year (percent)	Cumulative Right-of-Way Takings (dollars)	Inflation of Previous Years (dollars)	Cumulative Right-of-Way Takings After Inflation (dollars)
1953	931,200	–				931,200
1954	389,300	–	1.0[a]	1,320,500	9,300	1,329,800
1955	46,800	0.9338	1.0[a]	1,367,300	13,300	1,389,900
1956	121,350	–	1.0[a]	1,488,650	13,900	1,525,150
1957	602,450	0.979	1.0[a]	2,091,100	15,250	2,142,850
1958	1,316,600	1.006	2.8	3,407,700	60,000	3,519,450
1959	2,050,610	1.0152	0.8	5,458,310	25,300	5,595,360
1960	666,380	1.0299	1.6	6,124,690	89,500	6,351,240
1961	405,640	1.0417	1.1	6,530,330	69,850	6,826,730
1962	2,801,540	1.0537	1.2	9,331,870	81,900	9,710,170
1963	3,676,420	1.0672	1.2	13,008,290	116,500	13,503,090
1964	3,936,650	1.0811	1.3	16,944,940	175,550	17,615,290
1965	2,711,930	1.0989	1.7	19,656,870	209,500	20,626,720
1966	4,008,050	1.1312	2.9	23,664,920	598,200	25,232,970
1967	2,651,566	1.1628	2.8	26,316,486	652,300	28,536,836
1968		1.2121	4.2		1,198,550	29,735,386
1969		1.2788	5.4		1,605,714	31,341,100
1970		1.3491	5.5		1,723,760	33,064,860

[a]From 1954 to 1957, an increase in the Consumer Price Index of 1.0 percent/year was assumed.

Table 2. Lost tax dollars and annual cost to average property owner.

Year	Assessed Value of Cumulative Right-of-Way Takings[a] (dollars)	Total Annual City Tax Rate[b] (dollars)	Total Tax Lost (dollars)	Market Value of City Real Estate (billions of dollars)	Cost per Individual[c] (dollars)
1953	931,200	47.51	44,240	2.206	0.40
1954	1,329,800	49.85	66,290	2.352	0.56
1955	1,389,900	51.29	71,290	2.489	0.57
1956	1,525,150	53.28	81,260	2.653	0.61
1957	2,142,850	55.26	118,410	2.821	0.84
1958	3,519,450	59.37	208,950	2.940	1.42
1959	5,595,360	58.20	325,650	3.002	2.17
1960	6,351,240	60.78	386,030	3.112	2.48
1961	6,826,730	63.68	434,730	3.144	2.77
1962	9,710,170	66.62	646,890	3.203	4.04
1963	13,503,090	68.57	925,910	3.199	5.79
1964	17,615,290	71.622	1,261,640	3.242	7.78
1965	20,626,720	72.512	1,495,680	3.287	9.10
1966	25,232,970	74.565	1,881,500	3.337	11.28
1967	28,536,836	80.969	2,310,600	3.492	13.23
1968	29,735,386	88.969	2,645,530	3.607	14.67
1969	31,341,100	88.140	2,762,400	3.774	14.64
1970	33,064,860	93.493	3,091,330	4.065	15.21

[a]After inflation. [b]Rate per $1,000 assessed value. [c]$20,000 property owner.

Table 3. Motor vehicle registrations and vehicle miles (kilometers) of travel.

Year	Motor Vehicle Registrations				VMT (in billions)	
	Milwaukee[a]	Milwaukee County	Wisconsin	City Percent of State Registration	Wisconsin	Milwaukee
1962	247,215	370,693	1,666,853	14.83	16.86	1.870
1963	256,640	384,826	1,785,149	14.37	17.51	1.941
1964	260,854	391,144	1,793,305	14.54	18.14	1.973
1965	278,002	412,238	1,893,867	14.67	19.19	2.102
1966	281,991	422,838	1,945,848	14.49	20.15	2.133
1967	295,035	442,397	2,055,009	14.35	20.92	2.231
1968	301,429	453,981	2,135,711	14.11	21.81	2.279
1969	301,515	454,621	2,153,407	14.00	23.89	2.280
1970	307,302	461,230	2,210,492	13.90	24.50	2.324

Note: 1 mile = 1.6 km.

[a]Actual figures were available for 1965 and 1968 through 1970 only. Other years were estimated from Milwaukee County registration figures.

Table 4. Accident rates for Milwaukee.

Year	VMT (in billions)	Accidents			Accident Rate per Billion VMT		
		Fatalities[a]	Nonfatal Injuries	Property Damage Only	Fatalities	Nonfatal Injuries	Property Damage Only
1962	1.870	52	6,163	10,224	27.8	3,296	5,467
1963	1.941	61	6,864	10,142	31.4	3,536	5,225
1964	1.973	75	7,230	10,713	38.0	3,664	5,430
1965	2.102	61	8,193	12,078	29.0	3,898	5,746
1966	2.133	59	8,358	12,259	27.7	3,918	5,747
1967	2.231	65	8,762	12,287	29.1	3,927	5,507
1968	2.279	73	8,671	12,172	32.0	3,805	5,341
1969	2.280	71	8,927	14,105	31.1	3,915	6,186
1970	2.324	67	8,955	12,332	28.8	3,853	5,306

Note: 1 mile = 1.6 km. 1 accident/vehicle mile of travel = 0.625 accident/vehicle km of travel.

[a]Does not include fatalities on freeways inside the corporate limits of the city of Milwaukee.

the average weekday travel respectively according to information we received from the Transportation Division of the Southeastern Wisconsin Regional Planning Commission. Based on these data, total travel on the arterial and nonarterial streets of Milwaukee during 1963 was estimated to be 1,940,820,000 vehicle miles (3 124 720 200 vehicle km). The estimates of vehicle miles (kilometers) for the other years were derived on the basis of motor vehicle registration data as given in Table 3 (4, 5).

The procedure for calculating the city's VMT (vehicle kilometers of travel) was received from the Transportation Division of the Southeastern Wisconsin Regional Planning Commission. Accident rates for the city of Milwaukee are given in Table 4.

A summary of accident rates for the Milwaukee County freeway system for 1962 to 1970 is given in Table 5 (6). Accident rates for the city's arterial and nonarterial street system then were compared with those of the Milwaukee County freeway system, and the number of accidents eliminated in each category because of the freeway system was estimated. The underlying assumption of this procedure is that, in the absence of the freeway system, the travel that took place on the freeways would have been made on the other arterial and nonarterial streets. Although this assumption may be questioned because an improved transportation service often generates new traffic, the assumption was consistent with that underlying the current urban transportation planning methodology for number of trips. The results are given in Table 6.

When the number and types of accidents eliminated by the freeways in Milwaukee County were determined, the savings in monetary terms for each year were determined based on the values set by the National Safety Council. The National Safety Council information was available for 1963, 1964, and 1970, and the values for the other years were estimated on the basis of changes in the CPI. The yearly costs of accidents eliminated are given in Table 7. A portion of this savings then was assigned to Milwaukee based on the ratio of city to county motor vehicle registrations. The assigned amount was approximately 67 percent of the total accident savings and is given in Table 8. (The procedure adopted to assign accident savings to the city seemed to be reasonable because, from 1964 to 1969, when the County Sheriff's Department broke down accident occurrences by municipality, 73 percent of the total accidents within the county occurred within the city of Milwaukee.)

After obtaining the annual accident savings that accrued to the city of Milwaukee ($25,361,114), we sought a method of estimating the amount of savings for a unit property taxpayer. The market value of total city real estate was known. Therefore, a simple ratio was used to apportion the total savings to a $20,000 real estate property. The results of this analysis, given in Table 8, indicate a total return of $138.30 to the individual taxpayer in reduced accident costs.

SAVINGS IN TRAVEL TIME COST

For this study, travel time savings that accrued to city residents were based on their use of freeways inside city limits. Time savings for the use of freeways outside the city were not considered. Because of the nature of the available data, a few assumptions had to be made about the volume of traffic for city residents and their routes of travel. Initially, the travel time savings were determined for the movements between the freeway entrance ramps in the city to the central business district (CBD) by comparing the travel time necessary to go from freeway entrance ramps to the CBD with the time necessary to go from alternative arterial routes to the CBD. The information on travel times was obtained from 1970 information provided by the Southeastern Wisconsin Regional Planning Commission. The time savings between CBD and freeway entrance ramps were used in estimating the travel time savings between appropriate pairs of entrance ramps for movements not having destinations in the CBD. Because the Marquette interchange near the CBD was opened in December 1968, the travel time data based on the 1970 network were valid for 1969 and 1970 only. A summary of the results is given in Table 9. Analysis for the other years will be discussed later.

For macroanalysis, the Southeastern Wisconsin Regional Planning Commission divided the 7-county region into 15 districts, and the travel information between these

Table 5. Accident rates for Milwaukee County freeways.

		Accidents			Accident Rate per Billion VMT		
Year	VMT (in billions)	Fatalities	Nonfatal Injuries	Property Damage Only	Fatalities	Nonfatal Injuries	Property Damage Only
1962	0.064	0	45	134	—	703	2,094
1963	0.116	1	150	296	8.6	1,293	2,552
1964	0.305	7	284	516	23.0	931	1,692
1965	0.300	3	288	603	10.0	960	2,010
1966	0.366	10	461	741	27.3	1,260	2,025
1967	0.577	8	751	1,203	13.9	1,302	2,085
1968	0.882	12	809	1,564	13.6	917	1,773
1969	1.106	19	1,301	2,417	17.2	1,176	2,185
1970	1.165	28	1,133	2,425	24.0	973	2,082

Note: 1 mile = 1.6 km. 1 accident/vehicle mile of travel = 0.625 accident/vehicle km of travel.

Table 6. Accidents eliminated by Milwaukee County freeways.

		Difference in Rates (accidents per billion VMT)			Accidents Eliminated[a]		
Year	VMT (in billions)	Fatalities	Nonfatal Injuries	Property Damage Only	Fatalities	Nonfatal Injuries	Property Damage Only
1962	0.064	27.8	2,593	3,373	2	166	216
1963	0.116	22.8	2,243	2,673	3	260	310
1964	0.305	15.0	2,733	3,738	5	834	1,140
1965	0.300	19.0	2,938	3,736	6	881	1,121
1966	0.366	0.4	2,658	3,722	—	973	1,362
1967	0.577	15.2	2,625	3,422	9	1,515	1,974
1968	0.882	18.4	2,888	3,568	16	2,547	3,147
1969	1.106	13.9	2,739	4,001	15	3,029	4,425
1970	1.165	4.8	2,880	3,224	6	3,355	3,756[b]

Note: 1 mile = 1.6 km. 1 accident/vehicle mile of travel = 0.625 accident/vehicle km of travel.

[a]Determined by multiplying difference in rates by freeway vehicle miles (kilometers) of travel.

[b]Milwaukee Police Department no longer sends squads to accidents involving property damage only, which has caused a significant decrease in the number of reported property damage accidents in the city.

Table 7. Accident cost savings for Milwaukee County freeways.

	Accidents Eliminated			Cost (dollars)			
Year	Fatalities	Injuries	Property Damage Only	Fatalities	Injuries	Property Damage Only	Savings (dollars)
1962	2	166	216	32,900	1,850	310	439,860
1963	3	260	310	33,300	1,900	310	690,000
1964	5	834	1,140	34,400	1,800	310	2,026,600
1965	6	881	1,121	35,000	1,850	310	2,187,360
1966	—	973	1,362	36,000	1,950	315	2,326,380
1967	9	1,515	1,974	36,900	2,050	320	4,069,530
1968	16	2,547	3,147	38,400	2,150	340	7,160,430
1969	15	3,029	4,425	40,100	2,300	360	9,161,200
1970	6	3,355	3,756	41,700	2,500	380	10,064,980

Table 8. Accident cost savings for Milwaukee.

Year	City Percent of County Vehicle Registration	Savings to County (dollars)	Savings to City (dollars)	Real Estate Market Value of Milwaukee (billions of dollars)	Accident Savings per Individual[a] (dollars)
1962	66.49	439,860	292,463	3.203	1.83
1963	66.49	690,000	458,781	3.199	2.87
1964	66.49	2,026,600	1,347,486	3.242	8.31
1965	67.43	2,187,360	1,474,937	3.287	8.97
1966	66.49	2,326,380	1,546,810	3.337	9.27
1967	66.49	4,069,530	2,705,830	3.492	15.50
1968	66.39	7,160,430	4,753,809	3.607	26.36
1969	66.32	9,161,200	6,075,708	3.774	32.20
1970	66.62	10,064,980	6,705,290	4.065	32.99

[a]$20,000 property owner.

districts was used in this analysis. Districts 1, 2, 4, 14, and 15 include most of the city. Because of the number of city residents in each of the 5 districts and their expected travel pattern, we decided that the estimates of travel time savings that accrued to the city residents would be derived on the basis of travel to and from districts 2 and 4 only. It appeared that the limited analysis would not alter the results of the study significantly although it would understate the benefits to some extent.

Tables 10, 11, 12, and 13 give 1963 vehicle trip data between districts 2 and 4 and other districts. These trip volumes were assumed to remain constant throughout the analysis period (1962 through 1970). The assumption, of course, resulted in a conservative estimate of travel time savings; but, in the absence of reliable data for subsequent years, we considered this approach to be a reasonable compromise. The expected use of freeways and their ramps is given in Tables 11 and 13. The assumptions used in developing the travel data are as follows:

1. Only district-to-district movement oriented toward freeways in the city was considered;
2. Percentage of total trips involving ramp use in travel between 2 districts was based on the percentage of total 1970 ramp count for the districts;
3. The ramps within the area bounded by a line north of North Avenue, west of Twenty-Seventh Street, and south of Lincoln Avenue were assumed to be CBD ramps, and no travel time saving for CBD trips was considered for these ramps;
4. Percentage of freeway trips between 2 districts was based on total 1970 ramp count for the districts; and
5. All long trips outside Milwaukee County by city residents were made on the freeway.

The time savings estimated by using the vehicle trips in Tables 10, 11, 12, and 13 and the travel time data given in Table 9 represent the average weekday savings of travel time in vehicle minutes per day in 1969 and 1970. To obtain the travel time savings in vehicle hours per year, we assumed that

1. There were 260 weekdays per year;
2. Saturday traffic was 84.18 percent of weekday traffic;
3. Sunday traffic was 71.66 percent of weekday traffic; and
4. There are 52 Saturdays and 52 Sundays per year.

After obtaining the district-to-district travel time savings that accrued to all travelers, the amount of savings that could be assigned to Milwaukee residents was computed.

1. A set of city area factors was developed to reflect the amount of city land within each district and was expressed as a fraction of total district area. We assumed that the density of trip origins and destinations per square mile (square kilometer) was uniform throughout a given district. Accordingly, if 50 percent of the land area in the district being investigated was estimated to lie within the city of Milwaukee, then 50 percent of the district-to-district trips were assigned to city residents for computation of travel time savings.
2. A set of district-to-district factors was developed on the basis of 1963 county-to-county work trips (1). The district-to-district factor indicated the ratio of work trips originating at Milwaukee to work trips originating at other districts. These factors were applied to all types of trips.

A summary of annual district-to-district travel time savings for districts 2 and 4 and the savings assigned to the city of Milwaukee are given in Tables 14 and 15. These time savings for the years 1969 and 1970 then were converted to monetary values by assuming the cost of travel time to be \$1.75/vehicle hr and \$1.85/vehicle hr for 1969 and 1970 respectively. The unit values for travel time were obtained by adjusting the value of \$1.55/vehicle hr, which was used by the Southeastern Wisconsin Regional Planning Commission (2). The total dollar value of travel time savings that accrued to the city

Table 9. Point-to-point travel time saved Milwaukee city freeways in 1969 and 1970.

Enter Freeway Ramp	Exit Freeway Ramp	Time Saved (min)	Enter Freeway Ramp	Exit Freeway Ramp	Time Saved (min)
Capitol	CBD	1.10	Keefe	CBD	0.90
	35th	1.50		35th	1.30
	Hawley	3.00		Hawley	2.80
	68th	3.15		68th	2.95
	84th	3.20		84th	3.00
	Holt	1.70		Holt	1.50
	Howard	2.10		Howard	1.90
	Layton	2.75		Layton	2.55
	College	3.25		College	3.05
Locust	CBD	0.80	35th	CBD	0.40
	35th	1.20		Holt	1.00
	Hawley	2.70		Howard	1.40
	68th	2.85		Layton	2.05
	84th	2.90		College	2.55
	Holt	1.40		W. Good Hope	2.60
	Howard	1.80	Hawley	CBD	1.90
	Layton	2.45		Holt	2.50
	College	2.95		Howard	2.90
	State	1.20		Layton	3.55
Lisbon	CBD	0.90		College	4.05
	College	3.05		84th	0.20
	84th	0.70		W. Good Hope	1.10
68th	CBD	2.05	84th	CBD	2.10
	Holt	2.65		Holt	2.70
	Howard	3.05		Howard	3.10
	Layton	3.60		Layton	3.65
	College	4.20		College	4.25
National	CBD	1.05	Lloyd	CBD	0.80
	Locust	1.85		College	2.95
	Keefe	1.95		84th	0.60
	Capitol	2.25	State	CBD	0.30
	W. Good Hope	1.70		Holt	0.90
	84th	0.85		Howard	1.20
W. Good Hope	Hampton	0.90		Layton	1.95
	68th	0.90		College	2.45
	84th	0.90		84th	0.30
College	CBD	2.15			

Table 10. Total district 2 vehicle trips in 1963.

District-to-District Trips	Total Vehicle Trips	Total Freeway Trips	Percent on Freeway
2 to 1	60,637	12,120	20
2 to 4	60,116	12,020	20
2 to 5	19,925	9,960	50
2 to 9 through 11	9,190	9,190	100
2 to 12	440	440	100
2 to 13	4,121	4,121	100

Table 11. Entering and exiting percentages for district 2 vehicle trips in 1963.

District-to-District Trips	Percent Entering Using On Ramp			Percent Exiting										
				Using Off Ramp									From City	
	Capitol	Keefe	Locust	CBD	35th	Hawley	68th	84th	National	Holt	Howard	Layton	84th	College
2 to 1	40	20	40	100										
2 to 4	40	20	40	25	25	20	10	5	15					
2 to 5	40	20	40							25	30	15		30
2 to 9 through 11	40	20	40										100	
2 to 12	40	20	40										100	
2 to 13	40	20	40											100

Table 12. Total district 4 vehicle trips in 1963.

District-to-District Trips	Total Vehicle Trips	Total Freeway Trips	Percent on Freeway
4 to 1	74,078	18,520	25
4 to 3	4,075	4,075	100
4 to 6	4,245	4,245	100
4 to 7	4,770	4,770	100
4 to 9 and 11	39,750	39,750	100
4 to 12	1,789	1,789	100
4 to 13	8,581	8,581	100

Table 13. Entering and exiting percentages for district 4 vehicle trips in 1963.

District-to-District Trips	Percent Entering Using On Ramp									Percent Exiting				
										Using Off Ramp at CBD	From City			
	84th	68th	Hawley	35th	National	Lisbon	Lloyd	State	CBD		Locust	W. Good Hope	84th	College
4 to 1	10	12	9	12	17	19	12	9	0	100				
4 to 3	7	8	6	9	12	NT*	NT*	6	30		100			
4 to 6	7	8	6	9	12	NT*	NT*	6	30		100			
4 to 7	7	8	6	9	12	NT*	NT*	NT*	30			100		
4 to 9 and 11	NT*	NT*	6	9	12	13	9	6	30				100	
4 to 12	NT*	NT*	6	9	12	13	9	6	30				100	
4 to 13	7	8	6	9	12	13	9	6	30					100

*No trips or no time saving.

residents of districts 2 and 4 in 1969 and 1970 was estimated to be \$713,641 and \$754,421 respectively. These savings for a \$20,000 property taxpayer were found to be \$3.78 and \$3.71 for 1969 and 1970 respectively.

As mentioned previously, freeway use before the opening of the Marquette interchange was relatively lower. The estimate of travel time savings for the first 7 years of operation of the partially completed freeway system, therefore, was made on the basis of a comparison of annual freeway VMT (vehicle kilometers of travel) in the county during different periods. VMT for 1962 through 1966 was 11.51×10^8 (18.53×10^8 vehicle km of travel). For 1967 to 1968 the VMT was 14.59×10^8 (23.49×10^8 vehicle km of travel) compared with 11.65×10^8 (18.76×10^8 vehicle km of travel) in 1970. The costs of travel time during the periods 1962 through 1966 and 1967 to 1968 were assumed to be \$1.55/vehicle hr and \$1.65/vehicle hr respectively. The dollar values of travel time savings during the 1962 through 1966 and 1967 to 1968 periods then were computed by applying ratios of freeway VMT (vehicle kilometers of travel) and the value of time. This analysis yielded a total savings of \$624,486 for 1962 through 1966 and \$842,665 for 1967 to 1968. The savings for these 2 periods for the owner of a \$20,000 property were \$3.84 and \$4.75 respectively.

SAVINGS IN VEHICLE OPERATING COSTS

One of the significant advantages of freeways over regular city streets is the smoother flow of traffic. This results in reduced vehicle operating costs per mile (kilometer). This aspect of freeway-related benefits was examined, and the estimated annual savings in vehicle operating costs due to the freeways in Milwaukee County are given in Table 16. It was assumed that the VMT (vehicle kilometers of travel) that actually occurred on freeways would have occurred on city streets if there were no freeways. This assumption may not be fully accurate because freeways might generate some new traffic, but the assumption was consistent with the approach used in current urban transportation planning studies except that the freeway-oriented routes may be longer than alternative arterial routes for some trips. It appeared, however, that the overestimation of savings in operating costs, if any, would be insignificant for this study and would be offset by the conservative approach used in estimating some of the other benefits.

The operating costs on freeways and arterial streets used in this analysis were 5.94 and 6.10 cents/vehicle mile (3.69 and 3.79 cents/vehicle km) respectively for 1963 and were the same as those used by the Southeastern Wisconsin Regional Planning Commission (2). Since freeway-caused savings in vehicle operating costs are greater for trucks than for automobiles, an adjustment factor for trucks (1.1228) was used (2). The freeway VMT (vehicle kilometers of travel) multiplied by the difference in operating costs and the truck factor yielded the savings in operating costs attributable to freeways.

Based on the annual operating cost savings that accrued to the users of the Milwaukee County freeway system, the savings that accrued to the city residents as a whole and to owners of \$20,000 properties were estimated by using a procedure similar to that used for the analysis of accident cost savings. The results are given in Table 16.

SAVINGS FROM REDUCED NEED FOR ADDITIONAL ARTERIALS

The cost of constructing the freeway segments in the city of Milwaukee was reported to be \$211 million. If utility costs are deducted, the total is \$200.3 million (7). The freeway system in the city of Milwaukee consisted of both Interstate and non-Interstate highways, and Milwaukee County participated in financing both classes of freeways. The total share of the cost of the freeways inside the city that was borne by the county was \$22,203,000 (7). Because city residents paid approximately 58 percent of the total county property tax, we assumed that the city's share of the county's participation in freeway construction inside the city of Milwaukee was \$12,900,000.

Table 14. District 2 annual travel time savings for 1969 and 1970.

District-to-District Trips	Time Saved (vehicle hr/year)	City Area Factor	District-to-District Factor	Time Saved City Residents (vehicle hr/year)
2 to 1	64,750	0.75	1.00	48,560
2 to 4	194,775	0.65	1.00	126,605
2 to 5	130,295	0.75	0.50	48,860
2 to 9 through 11	158,695	0.75	0.20	23,805
2 to 12	7,605	0.75	0.50	2,850
2 to 13	72,305	0.75	0.50	27,115

Table 15. District 4 annual travel time savings for 1969 and 1970.

District-to-District Trips	Time Saved (vehicle hr/year)	City Area Factor	District-to-District Factor	Time Saved City Residents (vehicle hr/year)
4 to 1	120,695	0.50	1.00	60,350
4 to 3	28,540	0.50	0.20	2,855
4 to 6	29,880	0.50	0.25	3,735
4 to 7	41,685	0.50	0.14	2,920
4 to 9 and 11	231,860	0.50	0.20	23,185
4 to 12	10,735	0.50	0.50	2,685
4 to 13	124,615	0.50	0.55	34,270

Table 16. Vehicle operating cost savings for Milwaukee County freeways.

Year	VMT (in billions)	Annual Operating Cost Savings (1963 dollars)	Adjusted Annual Operating Cost Savings[a] (dollars)	Annual Operating Cost Savings Assigned to City (dollars)	Annual Operating Cost Savings per Individual[b] (dollars)
1962	0.064	114,975	113,612	75,541	0.47
1963	0.116	208,392	208,392	138,560	0.87
1964	0.305	547,926	555,049	369,052	2.28
1965	0.300	538,944	555,112	374,312	2.28
1966	0.366	657,512	696,305	462,973	2.77
1967	0.577	1,036,569	1,126,751	749,177	4.29
1968	0.882	1,584,495	1,788,895	1,187,647	6.59
1969	1.106	1,986,907	2,350,511	1,558,859	8.26
1970	1.165	2,092,900	2,591,010	1,726,131	8.49
Total		8,768,620	9,985,637	6,642,252	36.30

Note: 1 mile = 1.6 km.

[a]Adjusted for inflation based on consumer price indexes in Table 1.
[b]$20,000 property owner.

Table 17. Savings due to reduced need for additional arterials.

Year	Percent of Total	Savings (dollars)	Savings for Individual[a] (dollars)
1962	0	0	0
1963	10	290,000	1.81
1964	10	290,000	1.79
1965	5	145,000	0.88
1966	5	145,000	0.87
1967	5	145,000	0.83
1968	5	145,000	0.80
1969	20	580,000	3.07
1970	40	1,160,000	5.71
Total		2,900,000	15.67

[a]$20,000 property owner.

Table 18. Summary of quantified costs and benefits.

	Total Tax Loss (dollars)		Accident Savings (dollars)		Time Savings (dollars)		Vehicle Operating Cost Savings (dollars)		Savings From Reduced Need for Arterials (dollars)	
Year	City	Individual[a]	City	Individual[a]	City	Individual[a]	City	Individual[a]	City	Individual[a]
1953	44,240	0.40								
1954	66,290	0.56								
1955	71,290	0.57								
1956	81,260	0.61								
1957	118,410	0.84								
1958	208,950	1.42								
1959	325,650	2.17								
1960	386,030	2.48								
1961	434,730	2.77								
1962	646,890	4.04	292,463	1.83			75,541	0.47	0	0
1963	925,910	5.79	458,781	2.87			138,560	0.87	290,000	1.81
1964	1,261,640	7.78	1,347,486	8.31			369,052	2.28	290,000	1.79
1965	1,495,680	9.10	1,474,937	8.97			374,312	2.28	145,000	0.88
1966	1,881,500	11.28	1,546,810	9.27	624,486	3.84	462,973	2.77	145,000	0.87
1967	2,310,600	13.23	2,705,830	15.50			749,177	4.29	145,000	0.83
1968	2,645,530	14.67	4,753,809	26.36	842,665	4.75	1,187,647	6.59	145,000	0.80
1969	2,762,400	14.64	6,075,708	32.20	713,641	3.78	1,558,859	8.26	580,000	3.07
1970	3,091,330	15.21	6,705,290	32.99	754,421	3.71	1,726,131	8.49	1,160,000	5.71
Total	18,758,330	107.56	25,361,114	138.30	2,935,213	16.08	6,642,252	36.30	2,900,000	15.76

[a]$20,000 property owner.

If no freeways had been built in the city, then an additional burden would have been imposed on the existing street system. To maintain reasonable service, the city would have had to construct additional arterial streets. For this paper, we assumed that, in the absence of the freeway system, only 50 percent of the freeway travel volume would have had to be serviced by new surface arterial streets and that the other 50 percent would have used either existing surface arterials or public transit facilities. Based on these assumptions, we estimated that approximately 40.5 miles (65.21 kilometers) of additional 6-lane arterial surface streets costing approximately $54,475,000 for engineering, construction, and rights-of-way would have been required by 1970 within the city limits. This cost estimate is conservative and was based on average cost data for the county (3). If we assume a funding breakdown of 50 percent for state and federal sources and 50 percent for the county, then the share of the cost for Milwaukee County would be $27,237,500. The city's portion (58 percent of total county property tax) would be $15,797,750. A comparison of this cost for additional arterials with that for the freeways ($12,900,000) shows that freeways saved the city taxpayers approximately $2,900,000 in engineering, rights-of-way, and construction costs. The estimated distribution of this saving over the 9-year period and the savings that accrued to each $20,000 property taxpayer are given in Table 17.

CONCLUSIONS

Right-of-way takings for the freeway system in the city of Milwaukee resulted in the removal of real estate property leading to a tax loss of $18,758,330 from 1953 through 1970. However, a number of identifiable benefits accrued to the city residents that can be attributed to freeway construction. One of the significant benefits is increased traffic safety resulting in fewer accidents. The accident cost savings from 1962, when the first section of the freeway system was opened, through 1970 were estimated to be $25,361,114. The freeway system also contributed toward savings in travel time and vehicle operating costs, which were estimated to be $2,935,213 and $6,642,252 respectively for 1962 through 1970. In addition, it was estimated that the requirement for the city's capital improvement funds for the 9-year period, 1962 to 1970, was reduced by $2.9 million because the freeway system rather than additional arterial streets was constructed. Thus quantified benefits amounting to $37,838,579 were more than twice as much as the tax loss of $18,758,330. On an individual basis, the total benefit that accrued to a $20,000 property owner was estimated to be $206.44; the hypothetical tax increase was $107.56.

A summary of the freeway costs and benefits considered in this study is given in Table 18. The results show that, although the hypothetical tax loss became fairly stable in the later years of the analysis period, some of the benefits increased significantly during the last 2 years. Benefits increased during 1969 and 1970 because all of the major freeway segments were connected in December 1968, when the Marquette interchange was opened. Thus a comparison of the costs and benefits for 1969 to 1970 reveals more than a comparison for the entire 1953 to 1970 period. For the year 1970, the quantified benefits amounted to $10,345,842 and were more than 3 times greater than the corresponding tax loss of $3,091,330.

The scope of the analysis was limited to the quantifiable items for which data were available. Even for some of the items included in the analysis, the available data were not fully adequate, and many assumptions had to be made. However, a conservative approach was taken to ensure that the benefits were not overestimated. One of the direct effects of freeways excluded from the analysis is their environmental impacts, which include air and noise pollution. Among the indirect effects that also were not considered are impacts of freeways on the land development pattern and land value. An interesting phenomenon related to the tax base is the reinvestment by the displaced household, business, or industry in real estate property within the city limits. Such reinvestments offset the tax loss and thus reinforce the findings of this study.

It should be mentioned that in the recent years much attention has been focused on the question of the possible revitalization of Milwaukee's central business district by the freeway. A study indicated that, from the standpoint of property values, the Milwaukee CBD suffered no adverse effects because of the freeway (8). Considering all the facts and figures presented in this study, we concluded that the loss in the property tax for the city of Milwaukee due to freeway right-of-way takings was amply compensated for by benefits attributable to the freeway.

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DISCUSSION

Floyd I. Thiel, Federal Highway Administration

Batchelor, Sinha, and Chatterjee provided an interesting and unique approach to the question of highway effects on local taxes. They calculated that the average property taxpayer in Milwaukee receives freeway benefits in the form of fuel, time, and accident savings that exceed any additional property taxes he or she might pay as a result of taxable properties being lost because of freeway construction.

The study seems useful in several ways. For example, it estimates the savings a city government realizes when a limited-access highway (financed from noncity revenues) reduces costs for arterial streets. The study also provides a good perspective by noting that freeway acquisition reduced tax rolls by only 1.5 percent and by demonstrating that freeway-user benefits exceed tax roll losses without regard to the tax roll gains associated with freeways.

However, to deal with the problems the authors cite—property owners' concern about freeway effects on adjacent neighborhoods and city officials' concern for the lost tax base of their cities—the study needs to analyze some of the secondary effects Milwaukee freeways have on tax rolls. In fact, ignoring all but the initial freeway effects on the tax base and relating user savings to this initial tax base loss raise problems.

One problem is that credence may be given to a common misapprehension that highway construction lowers tax rolls. Another problem is that arraying freeway-user benefits to cover tax roll losses may result in counting these benefits twice because user benefits typically are considered to justify user costs.

I feel that a tax base study should deal with secondary or net effects of freeway construction and not only the initial loss that ordinarily accompanies right-of-way acquisition. Typically, such initial effects are offset by development or redevelopment near the highway or elsewhere. In Milwaukee, for example, the $33 million reduction in the tax rolls that occurred with right-of-way acquisition for freeways was accompanied by a gain in Milwaukee tax rolls of over $500 million during the period when right-of-way was being acquired. To some extent, the gains as well as the losses in tax rolls are related to freeway construction.

An analysis of Milwaukee tax records by Alice Randill of the Federal Highway Administration indicates that tax rolls near I-94 are increasing significantly faster than they are elsewhere. This is based primarily on tax roll changes for a 20-block area on both sides of I-94 compared with tax roll changes for a 19-block area of Milwaukee removed from I-94. The area studied extends along I-94 for about 1 mile (1.6 km) and is bounded generally by Third Street on the east side of I-94, Sixth Street on the west, Greenfield on the north, and Lincoln on the south. The control area also extends from Greenfield on the north to Lincoln on the south and from Fifteenth to Sixteenth Streets.

From 1959, before right-of-way acquisition began, to 1973, some time after I-94 opened, assessed values for residential and commercial properties changed from $2.8 to $3.9 million in the study area and from $3.0 to $3.3 million in the control area. This was a change in tax rolls of about 41 percent in the study area and 9 percent in the control area. The overall change for Milwaukee was 39 percent. Analysis and inspection of the study and control areas showed that the increase in tax rolls in the study area resulted from redevelopment and development of land parcels in the study area. This property improvement activity is especially apparent west of I-94. It probably is related partly to the construction of a new high school about halfway between the study and control areas. Both the study and control areas are substantially developed; most are residential; some are commercial. It seems significant that the rate of tax roll growth in the study area matches or exceeds that for Milwaukee as a whole where a higher portion of the land (about 25 percent) is undeveloped.

This apparent experience in Milwaukee appears fairly typical. Several studies have indicated that development and redevelopment and revaluation of land near highways often quickly offset tax roll losses that result from right-of-way acquisition (9, pp. 34-36). For officials concerned with taxes for public services, understanding these secondary effects on tax rolls seems more important than understanding the nature and calculation of benefits that accrue to individuals as highway users.

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AUTHORS' CLOSURE

We appreciate Thiel's discussion. The main purpose of our paper was to present benefit-cost analysis of an urban freeway system. Accordingly, we considered primarily those conventional benefit items such as savings in operating cost and travel time, accident cost reduction, and the elimination of costs such as those necessary for constructing additional surface arterials. The residents of a central city were taken as the affected group, and the possible loss in tax base was included as the only cost. The analysis, as mentioned in the paper, did not deal with the secondary benefits and costs associated with urban freeway construction. It was, however, recognized in the paper that, perhaps, a significant reinvestment by the displaced household, business, or industry in real estate property within the city occurred that offset the assumed tax loss. Furthermore, there is evidence, as mentioned in the paper and as supported by the data given by Thiel, that urban freeways have, in fact, increased adjacent property values. On the other hand, the urban freeways also may have contributed to air and noise pollution. However, in our paper a conservative approach was taken to ensure that the benefits were not overestimated and that the costs were not underestimated.

The remarks made by Thiel further reinforce the conclusions made by the authors that the freeway system has provided, in fact, some tangible benefits for the residents of the city of Milwaukee. We acknowledge that detailed research should be conducted to make a more complete benefit-cost analysis of urban freeway systems.

CLARIFYING THE AMBIGUITIES OF INTERNAL RATE OF RETURN METHOD VERSUS NET PRESENT VALUE METHOD FOR ANALYZING MUTUALLY EXCLUSIVE ALTERNATIVES

Martin Wohl, Carnegie-Mellon University

Many engineering economists have attempted to demonstrate that proper use of either the net present value method or the internal rate of return method to analyze mutually exclusive alternatives will result in identical and correct economic decisions. Unfortunately, however, the internal rate of return method, even when properly applied, often will result in either ambiguous or incorrect economic decisions. The purpose of this paper is to illustrate more completely and definitively the ambiguities that can occur and to show that the 2 methods cannot be reconciled without additional calculations, which, by definition, go beyond the internal rate of return method as strictly and properly applied.

•THE LITERATURE of economics and engineering economics is rich with articles and books dealing with the various methods of economic analysis for assessing and comparing alternative, mutually exclusive investment projects. Although the engineer's interest and knowledge in this subject has been sharpened, more often than not the various articles and books appearing within the engineer's domain are misleading, incorrect, or incomplete.

Consequently, I shall review 2 of the most popular benefit-cost analysis methods and, hopefully, demonstrate which method is appropriate or inappropriate for certain conditions and why.

BENEFIT-COST ANALYSIS DATA REQUIREMENTS

Let us assume that some given number of mutually exclusive engineering projects are being analyzed. Each of them will, in turn, lead to a series of present and future cost outlays (capital or operating) and to a stream of present and future benefits. The planning or analysis period and the minimum attractive rate of return (MARR), which also is known as the cutoff rate or opportunity cost of capital, will need to be known.

Analysis or Planning Period

It is important to analyze various investment proposals over the same analysis period to properly account for reinvestment of any earnings or benefits accrued before the end of the analysis (or replacement) period especially when one project may have a shorter terminal date than another (whether replaced or not) (2, pp. 74 ff.; 1, p. 233). There are, of course, many ways to ensure that projects are compared for the same periods of analysis. Some are explicit and some are not. For example, if project A has some capital items whose service life is so short that they must be replaced or terminated before the end of the planning or analysis period, then the application of a capital recovery factor to the initial capital outlay for rolling stock or other capital items will result in the implicit assumptions that (a) the capital items are perpetually replaced at the end of their service life and (b) the replacement costs of the capital items in future years will be exactly the same as they were when the project was started. A more appropriate analysis method would simply list the year-by-year cost outlays and benefits (or revenues, where appropriate) that are expected to occur in planning or analysis regardless of whether they change. This latter method at least permits both factor price and technological changes to be accounted for properly.

If a project is terminated rather than replaced before the end of planning, then benefit-cost comparisons will be valid as long as either the discounted benefit-cost ratio or net present value (NPV) methods are used and calculated with an appropriate discount or interest rate. The benefit-cost ratio method will not be discussed in detail in this paper, but, if it is properly applied, the decisions among alternatives will not differ from those of the net present value method when either discounted or equivalent annual benefits and costs are used even though more calculations will be required with the benefit-cost ratio method. On the other hand, use of the internal rate of return method will not always permit valid comparisons to be made among alternatives in the same case (1, pp. 234-241), or its use will result in ambiguities.

The following are essential points with which the analyst is concerned:

1. Examining the benefit and cost conditions expected to occur over the same analysis or planning period for all alternatives regardless of replacement or early termination and
2. Based on expected future benefits and costs, determining whether any initial capital outlays should be made at the present and, if so, which level of outlay is best.

For item 1, if a project among the set of alternatives is terminated early, the analyst must be concerned with other available opportunities for using the capital funds that would have been used for replacement and what returns (benefits or revenues) can be accrued from them. Similarly, when benefits or revenues are accrued in early years either before the end of the analysis period or before the terminal date of any project, the analyst cannot ignore the problem of properly accounting for the reinvestment or use of the early year benefits or revenues. Some of these matters will be clarified in later examples (1, pp. 234-241).

Opportunity Cost of Capital or Appropriate Discount or Interest Rate

In this paper, no attempt will be made to fully describe the difficulties and problems associated with choosing an appropriate discount or interest rate for use in some of the benefit-cost analysis methods (5, pp. 116-151). For each of the methods, though, an interest rate must be specified directly or indirectly. Often, and especially for the internal rate of return method, the interest rate to be specified is referred to as the minimum attractive rate of return, which reflects the interest that can be earned from foregone alternative opportunities. This term is equivalent to that used by economists, which is the opportunity cost of capital or an interest rate that reflects the earnings that will be foregone from other investment opportunities if the capital is to be committed to a project in question. To a large extent, the specification of an appropriate interest rate or MARR or opportunity cost of capital is arbitrary and thus open to question. Consequently, the analysis should be carried out for a range of interest rates. This range may reflect private market rates at one extreme and judgments about the social rate of discount at the other extreme. The range may vary widely from 3 to as much as 25 percent. However, 1 point is clear: The rate to be used in any analysis is usually not equal to the borrowing rate for bonds that must be floated to raise capital for a project.

METHODS OF BENEFIT-COST ANALYSIS

The net present value or net present worth and the discounted internal rate of return methods can be most easily described analytically.

Let

i = interest or discount rate (minimum attractive rate of return or opportunity cost of capital) in decimal form,
n = length of analysis period or planning horizon in years,
$C_{x,t}$ = expected cost outlays (capital or operating) for project x during year t, and
$B_{x,t}$ = expected benefits or revenues from project x during year t.

For convenience, it will be assumed that $B_{x,t}$ or $C_{x,t}$ will be accrued or committed in lump sum at the end of t. Typically, for other than the do nothing or abandonment alternative, that is, when $C_{x,0} = 0$, some initial cost outlays will occur in the beginning of the first year (when $t = 0$); benefits or revenues will not usually begin to accrue until at least a year later (when $t \geq 1$). In any case, though, the formulation is perfectly general and will apply to all situations. The cost and benefit streams during the n year planning period for any project x will look the same as those shown in Figure 1. In Figure 1, it is assumed that costs or benefits are incurred or accrued in a lump sum at the end of year t and that the costs or benefits during any year t can be 0.

A year-by-year cash flow tabulation of the benefits and costs for all alternatives in which, say, there are m alternatives and thus x varies from $x = 1, 2, \ldots, m$ could be displayed in much the same manner as that indicated for project x in Figure 1. However, the m alternatives should be ordered or ranked in ascending order so that alternative 1 is the alternative having the lowest initial cost in year $t = 0$ ($x = 1$), and alternative 2 is the alternative having the next lowest initial cost in year $t = 0$ ($x = 2$). The alternative having highest initial cost in year $t = 0$ is alternative m ($x = m$). These ranking or ordering rules can be applied to all the benefit-cost methods, but they are not necessary for the net present value method.

Net Present Value Method

With the net present value method, the benefits and costs are discounted to their present value or present worth, that is, to their value in year $t = 0$, and then netted to determine the resultant net present value. Determined analytically for project x, $NPV_{x,n}$, the net present value for the n-year analysis period, is

$$NPV_{x,n} = \sum_{t=0}^{n} \frac{1}{(1+i)^t} \cdot B_{x,t} - \sum_{t=0}^{n} \frac{1}{(1+i)^t} \cdot C_{x,t} \qquad (1)$$

or

$$NPV_{x,n} = \sum_{t=0}^{n} \frac{1}{(1+i)^t} \cdot (B_{x,t} - C_{x,t}) \qquad (2)$$

where

$\frac{1}{(1+i)^t}$ = present worth factor for year t, which is a factor for reducing future benefits or costs to present day values, and
i = minimum attractive rate of return or opportunity cost of capital in decimal form.

For each alternative, from $x = 1$ to $x = m$, the net present value must be determined.

In turn, the alternative having the highest nonnegative net present value is selected as best from an economic standpoint.

The net present value method is straightforward and guarantees that public or private agencies will maximize their net benefits or profits for any type of measurement, planning period, or interest rate. When the opportunity cost of capital (discount rate for other investments) is unknown or questionable, the calculations can be repeated for different rates, and the final results can be compared for similarities or differences in ranking. Also, if one should move from a lower initial cost alternative to a higher initial cost alternative, the net present value increases, and one may be certain that the discounted incremental or extra benefits outweigh the discounted extra costs.

There is no more easily applied, unambiguous, and less tedious benefit-cost analysis method than the net present value method. Moreover, the method is just as applicable to situations in which there is a budget constraint and the problem is to select the most worthwhile set of projects among a larger group of alternatives. In such a case, one simply combines those projects whose total initial costs are less than or equal to the budget constraint but whose combined total net present value is largest.

Discounted Internal Rate of Return Method

The discounted internal rate of return method has been popularized increasingly by engineering economists although, oftentimes, it has been improperly explained or used. Most important, though, this method can result in the making of improper or incorrect economic choices. More recently, Bergmann (6, p. 81) outlined a method that attempted to reconcile the results of the internal rate of return and net present value methods and avoid the ambiguities that can result from use of the internal rate of return method. He developed a rank ordering technique for alternatives that appeared to obviate the ambiguity that can result with certain investment cases; he did note, however, that his method was not general and "... applies only to situations where the rates of return on both the basic and incremental investments for each alternative are unique." The 3 examples to be contained in this paper will demonstrate that his special rank ordering technique indeed only applies when rates of return are unique and thus does not avoid the ambiguities and reconcile the different decisions that result from the rate of return and net present value methods in situations in which nonunique solutions occur.

As a consequence, a fully general technique will be outlined in this paper that will be explained in more detail for the more general 3-year and n-year cases. Hopefully, these examples and the accompanying explanation can clarify the matter and thus permit analysts to discard those methods that give incorrect or ambiguous answers when they evaluate mutually exclusive projects.

The discounted internal rate of return method has 2 essential steps (3, pp. 65-66; 1, pp. 230-232). In the first step, a MARR or opportunity cost of capital must be stated. This discount rate serves as the cutoff rate for accepting or rejecting projects being analyzed. Given this, the next step is to compute the internal rate of return for the lowest initial cost alternative (x = 1). The internal rate of return, r_x, for any project x can be determined analytically or iteratively by determining the rate of return value or discount rate, in decimal terms, that satisfies the following formulation. Find r_x, so that

$$\sum_{t=0}^{n} \frac{1}{(1+r_x)^t} \cdot B_{x,t} = \sum_{t=0}^{n} \frac{1}{(1+r_x)^t} \cdot C_{x,t} \qquad (3)$$

where $1/(1+r_x)^t$ = discount factor for internal rate of return method. If r_x is at least as large as the MARR, then alternative x is judged to be economically acceptable by this method. (A later example will show that this is not necessarily correct.)

The r_x for individual projects is determined, starting with alternative x = 1, until the lowest initial cost project having an acceptable internal rate of return ($r_x \geq$ MARR) is ascertained. This alternative, say, alternative x, then becomes the lowest cost-acceptable alternative.

The second step in the internal rate of return method is to determine the internal rate of return on increments of investment or initial cost over the lowest acceptable initial cost alternative. Again, if alternative x is the lowest acceptable initial cost alternative, then the internal rate of return on the increase in initial cost between x and the next higher initial cost alternative (x + 1) must be determined. Find $r_{x/x+1}$, the internal rate of return on the increase in investment or initial cost between alternative x and the next higher initial cost alternative x + 1, so that

$$\sum_{t=0}^{n} \frac{1}{(1+r_{x/x+1})^t} (B_{x+1,t} - B_{x,t}) = \sum_{t=0}^{n} \frac{1}{(1+r_{x/x+1})^t} (C_{x+1,t} - C_{x,t}) \quad (4)$$

where $1/(1+r_{x/x+1})^t$ = discount factor for internal rate of return on increment in initial cost. When the lowest initial cost alternative, say, x, having an acceptable rate of return ($r_x \geq$ MARR) is determined, then paired calculations for increasingly higher initial cost alternatives are made by using equation 4; if $r_{x/x+1}$ is at least as large as the MARR, then alternative x + 1 is accepted as a better alternative. If not, then alternative x + 1 is rejected, and a paired comparison is made between x and x + 2 and so forth until the highest initial cost alternative that satisfies both sets of rate of return calculations is determined. Under the internal rate of return method, the highest initial cost alternative satisfying these conditions will be selected as the best economically.

However, if the internal rate of return formula (equation 3) for any alternative x and the internal rate of return formula for the increment in initial cost found when one compares alternative x with x + 1 (equation 4) are rearranged, 2 formulations will result. Find r_x so that

$$\sum_{t=0}^{n} \frac{1}{(1+r_x)^t} \cdot (B_{x,t} - C_{x,t}) = 0 \quad (5)$$

This is identical to saying: The internal rate of return for any alternative x is exactly equivalent to the discount rate at which the net present value is 0. (Compare equations 3 and 5.) Find $r_{x/x+1}$ so that

$$\sum_{t=0}^{n} \frac{1}{(1+r_{x/x+1})^t} \cdot (B_{x+1,t} - C_{x+1,t}) = \sum_{t=0}^{n} \frac{1}{(1+r_{x/x+1})} \cdot (B_{x,t} - C_{x,t}) \quad (6)$$

This is identical to saying: The internal rate of return for increments of investment or initial cost between 2 alternatives is exactly equivalent to the discount rate at which the net present value of the 2 alternatives being compared is equal. (Compare equations 4 and 6.)

APPLICATION AND CRITIQUE OF NET PRESENT VALUE AND INTERNAL RATE OF RETURN METHODS

To apply and critique net present value and internal rate of return methods, let us consider 3 examples, 1 of which has been widely discussed (4, pp. 38-54; 1, pp. 241-243; 6) but is somewhat oversimplified and 2 others that are less well known but underscore the ambiguities of the internal rate of return method. For the last of these, the data were obtained from Bierman and Smidt (4, p. 55, problem 3-2).

Example 1

Assume the 2-year stream of benefits and costs given in Table 1. The 2 alternatives having equal initial costs but different benefits and costs in the following 2 years have been ranked according to the method suggested by Bergmann (6, p. 81) so that the first alternative, x = 1, is that which has the highest benefits during the first year. For the data in Table 1, r_x for alternative x = 1 is 25 percent; r_x for x = 2 is 20 percent; $r_{1 \text{ versus } 2}$ is ≈10.9 percent. These rates are given in percentages for convenience. Bergmann argues that, for alternatives having equal initial costs and a unique solution, unambiguous results occur whether one uses the net present value or whether one uses the internal rate of return method as long as the alternatives are ranked in the fashion that he suggests. That is, if the initial costs are equal, the first alternative is that which has the highest earnings or lowest costs, whichever applies, during the first year when t = 1. For this very special situation, one which is hardly applicable generally, Bergmann's ranking does produce identical results and reconcile the methods. But it would be misleading to suggest that the methods can be reconciled generally. For the data given in Table 1, the internal rate of return method would result in the selection of alternative x = 2 as long as the MARR was about 10.9 percent or less. For a MARR value above 10.9 percent but equal to or below 25 percent, alternative x = 1 is best. For higher MARRs, neither alternative would be selected. Calculations of the net present value at different interest rates would give identical decision results for these data and this case as shown in Figure 2.

Example 2

Assume the 2-year stream of benefits and costs given in Table 2. They will be ranked according to the rule outlined by Bergmann (6, p. 81). For the data in Table 2, r_x for alternative x = 1 is 20 and 1,580 percent; r_x for x = 2 is 25 and 1,022 percent; $r_{1 \text{ versus } 2}$ is ≈10.9 percent. Although the data used in Table 2 are not typical, they nonetheless will demonstrate the ambiguity that can result from using the internal rate of return method in the usual fashion even when alternatives are ranked in the manner outlined by Bergmann. For instance, given the data shown in Table 2 and the internal rates of return, a confusing and ambiguous set of conclusions will result if the analyst insists on applying the rate of return method in straightforward fashion without additional calculations. To be specific, he or she presumably would come to 1 of 2 sets of conclusions.

1. The high rates of return for alternatives x = 1 and x = 2 (1,580 and 1,022 percent respectively) should be ignored or rejected as unmeaningful. This means that (a) alternative x = 2 is best for a MARR equal to or less than 10.9 percent; (b) alternative x = 1 is best for a MARR between 10.9 and 20 percent; (c) alternative x = 2 is best for a MARR over 20 percent; and (d) no alternative is acceptable for a MARR greater than 25 percent.

2. The lower rates of return figures for alternatives x = 1 and x = 2 (20 and 25 percent respectively) should be ignored. This means that (a) alternative x = 2 is best for a MARR equal to or less than 10.9 percent; (b) alternative 1 is best for a MARR between 10.9 and 1,580 percent; and (c) no alternative is acceptable for a MARR greater than 1,580 percent.

Figure 1. Cost-benefit streams.

YEAR t	COSTS DURING YEAR t	BENEFITS DURING YEAR t
t = 0	$C_{x,0}$	$B_{x,0}$
1	$C_{x,1}$	$B_{x,1}$
.	.	.
.	.	.
t	$C_{x,t}$	$B_{x,t}$
.	.	.
.	.	.
t = n	$C_{x,n}$	$B_{x,n}$

Table 1. Cost and benefit data for example 1.

	Alternative x = 1 (dollars)		Alternative x = 2 (dollars)	
Year	$B_{1,t}$	$C_{1,t}$	$B_{2,t}$	$C_{2,t}$
t = 0	0	100	0	100
t = 1	100	0	20	0
t = 2	31.25	0	120	0

Note: Some numbers have been rounded for convenience.

Figure 2. Plot of net present value versus interest rate for example 1 data.

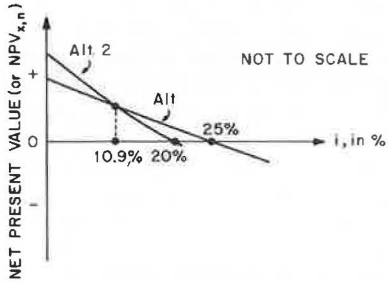


Table 2. Cost and benefit data for example 2.

	Alternative x = 1 (dollars)		Alternative x = 2 (dollars)	
Year	$B_{1,t}$	$C_{1,t}$	$B_{2,t}$	$C_{2,t}$
t = 0	0	100	0	100
t = 1	1,800	0	1,247	0
t = 2	0	2,016	0	1,403

Note: Some numbers have been rounded for convenience

Figure 3. Plot of net present value versus interest rate for example 2 data.

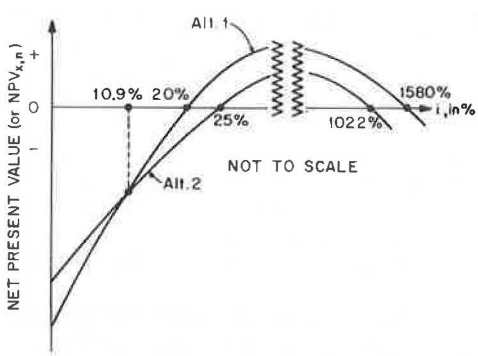
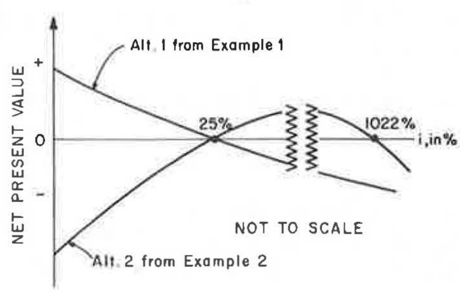


Figure 4. Plot of net present value versus interest rate for 2 examples when both have identical initial costs and basic internal rates of return.



It is evident that the 2 sets of conclusions are different. Thus which alternative is best under certain conditions is ambiguous. More important, though, is that both sets of conclusions are incorrect. To demonstrate this fact (not only for this example, but all others as well), one simply needs to tabulate or plot, approximately to scale, the net present values for each alternative versus the interest rate. That is, determine and plot the net present values for different MARRs. Figure 2 shows the plot for the data in example 1. Figure 3 shows the plot for the data in example 2. From the curves in Figure 3, it is simple to conclude the following for example 2: (a) No alternative is acceptable for a MARR below 20 percent; (b) alternative $x = 1$ is best for a MARR between 20 and 1,580 percent; and (c) no alternative is acceptable for a MARR higher than 1,580 percent. Clearly, this set of conclusions is far different from that which resulted from use of the internal rate of return method.

One cannot always properly interpret simple (discounted) internal rate of return calculations (including those for increments of investment over the lowest initial cost-acceptable alternative) without having additional information, which, by definition, is not part of the internal rate of return method. Thus, in some, if not most, cases, the methods and answers cannot be reconciled. One might argue that to end up with situations in which the net present value for alternatives can be negative at a zero discount or interest rate is hardly possible and certainly not typical. However, given that (a) both highway and transit systems are long lived (b) heavy capital outlays often must be made for 5 to 10 years before benefits begin to accrue, and (c) heavy capital and operating outlays are required in future years (for rolling stock, resurfacing, and repairs and maintenance), this eventuality seems possible, if not probable. In any case, the possibility of this occurrence alone should convince the engineering economist to abandon the deceivingly simple but sometimes inaccurate or ambiguous internal rate of return method.

Another way to highlight the ambiguities and the reasons for them is to compare alternative $x = 1$ from example 1 with alternative $x = 2$ from example 2. For both, the lowest basic internal rate of return was 25 percent and the initial cost was $100; for alternative $x = 2$ from example 2, the higher basic rate of return was 1,022 percent. In 1 case, the cutoff rate of return should be interpreted one way, in the other case it should be interpreted in another way. For instance, in Figure 4, the net present value versus interest rate curves have been plotted for these two alternatives. From this diagram it is obvious that alternative $x = 1$ from example 1 will be acceptable only if the MARR is 25 percent or less; alternative $x = 2$ from example 2 is acceptable only if the MARR is between 25 and 1,022 percent. This is apart from considering any changes associated with examining the return from increments of benefit and cost between alternatives.

These points can be made even more strongly by considering a third example, an example that has positive net present values at a 0 discount rate and no negative future benefits, but which covers a 3-year period and is seemingly more straightforward and generally applicable.

Example 3

Assume a 3-year stream of benefits and costs for the 3 alternatives as given in Table 3. The internal rates of return for the 3 alternatives were computed by using equation 3, and the paired internal rates of return for increasingly higher cost alternatives were computed using equation 4. For the data in Table 3, r_x for alternative $x = 1$ is 24 percent; r_x for alternative $x = 2$ is 20 percent; and r_x for alternative $x = 3$ is 21 percent. $r_{1\ \text{versus}\ 2}$ is 19.7 percent; $r_{2\ \text{versus}\ 3}$ is 15.7 and 271 percent; and $r_{1\ \text{versus}\ 3}$ is 20.7 percent. The questions are: Under what conditions is which alternative best according to internal rate of return and net present value methods, and what is the reason for the differences when the answers differ?

If we apply the internal rate of return method, we first cannot fail to note that there are multiple rates of return (2 real and positive discount rates) that satisfy equation 4 when we compare the extra costs and extra benefits of alternatives 2 and 3. Thus we are faced with an obvious ambiguity about which rate is the correct cutoff rate or which one to use in what instance. Moreover, the ambiguity cannot be clarified without carrying out at least some net present value calculations to supplement the rate of return results previously given. At any rate, before doing additional calculations, one can draw certain conclusions about which alternative is best by strictly applying the internal rate of return method.

1. If the MARR or opportunity cost of capital is equal to or less than 24 percent, then alternative x = 1 is acceptable.

2. If the MARR is equal to or less than 15.7 percent, then alternative x = 1 is acceptable (because r_1 is greater than 15.7 percent); in turn, because the return on the increment of investment between alternatives x = 1 and x = 2 is 19.7 percent and is greater than 15.7 percent, alternative x = 2 should be selected as being more acceptable than x = 1. Similarly, because the return on the extra investment of alternative x = 3 over alternative x = 2 is either 15.7 or 271 percent, it would appear that alternative x = 3 may be preferable to x = 2 and is acceptable (because r_3 is greater than 15.7 percent). Nevertheless, the answer is ambiguous.

3. If the MARR is greater than 15.7 percent but equal to or less than 19.7 percent, then alternative x = 1 will be acceptable (because r_1 is greater than 19.7 percent); also, because the return on the extra investment between alternatives x = 1 and x = 2 is equal to the highest MARR value (because $r_{1\ \text{versus}\ 2}$ is 19.7 percent), then clearly alternative x = 1 should be rejected in favor of alternative x = 2. On the other hand, because the return on the extra investment between alternatives x = 2 and x = 3 is either 15.7 or 271 percent and because which rate applies under what conditions is ambiguous, it is difficult to say whether alternative x = 2 or alternative x = 3 is better for a MARR range greater than 15.7 percent but equal to or less than 19.7 percent.

4. If the MARR is greater than 19.7 percent but equal to or less than 20.7 percent, then alternative x = 1 is acceptable (because r_1 is greater than 19.7 percent); but the additional investment to move to alternative x = 2 is economically unacceptable because $r_{1\ \text{versus}\ 2}$ is not more than 19.7 percent and thus alternative x = 2 must be rejected in favor of x = 1. In turn, on examining the return on the additional investment in going from x = 1 to x = 3, we find that the extra return, or $r_{1\ \text{versus}\ 3}$, is 20.7 percent and thus is acceptable; accordingly, for this MARR range, alternative x = 3 is judged to be the best acceptable alternative.

5. If the MARR is greater than 20.7 percent but equal to or less than 24 percent, then alternative x = 1 is clearly acceptable. But, because the return on the increment of investment from x = 1 to x = 2 is less than 20.7 percent ($r_{1\ \text{versus}\ 3}$ = 19.7 percent), alternative x = 2 must be rejected in favor of alternative x = 1. Similarly, because the return on the extra investment between alternatives x = 1 and x = 3 ($r_{1\ \text{versus}\ 3}$ = 20.7 percent) is less than the previously stated MARR (which is more than 20.7 percent), alternative x = 3 must be rejected and alternative x = 1 must be accepted as the best acceptable alternative.

6. If the MARR is more than 24 percent, then all alternatives must be rejected because r_x for x = 1, 2, 3 are all equal to or less than the MARR.

The results for the internal rate of return analysis, strictly applied, are given in Table 4. If the analyst had failed to note the multiple rates of return when comparing alternatives x = 2 and x = 3, and had simply overlooked the seemingly unrealistic 271 percent rate of return (which is a valid root), the results would have been even more misleading, and, in fact, incorrect. Specifically, if the 271 percent rate for alternative x = 2 versus alternative x = 3 had been ignored and only the 15.7 percent figure considered, then the Table 4 results would have indicated that alternative x = 3 was best for a MARR less than 15.7 percent and that alternative x = 2 was best for a MARR greater than 15.7 percent but equal to or less than 19.7 percent; for other ranges of interest the answers would not differ. However, as one can see from Figure 5 and other items to be discussed, these results would definitely be incorrect and would cause bad economic decisions.

For this particular example, where the net present values for all alternatives were

Table 3. Cost and benefit data for example 3.

Year	Alternative x = 1 (dollars)		Alternative x = 2 (dollars)		Alternative x = 3 (dollars)	
	$B_{1,t}$	$C_{1,t}$	$B_{2,t}$	$C_{2,t}$	$B_{3,t}$	$C_{3,t}$
t = 0		1,000		10,000		11,000
t = 1	505	0	2,000	0	5,304	0
t = 2	505	0	2,000	0	5,304	0
t = 3	505	0	12,000	0	5,304	0

Note: Some numbers have been rounded for convenience.

Table 4. Best alternatives under internal rate of return analysis.

Range for MARR (percent)	Best Acceptable Alternative
≤15.7	x = 2 or x = 3[a]
>15.7 but ≤19.7	x = 2 or x = 3[a]
>19.7 but ≤20.7	x = 3
>20.7 but ≤24	x = 1
>24	None

[a]Answer is ambiguous.

Figure 5. Plot of net present value versus interest rate for example 3 data.

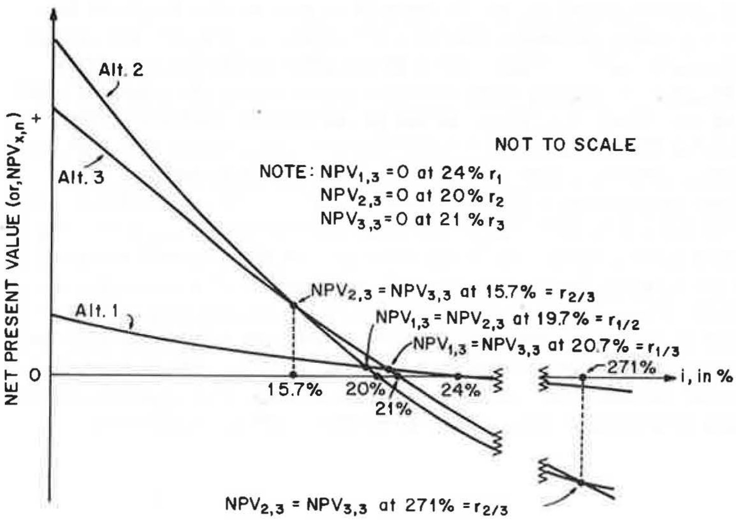
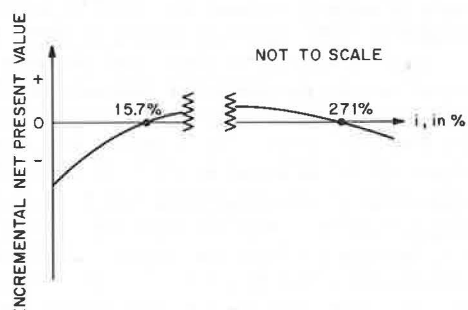


Figure 6. Plot of incremental net present value versus interest rate for incremental costs and benefits between alternatives x = 2 and x = 3 for example 3.



positive at a 0 discount rate (i = 0), the ambiguities arise from the complications associated with interpreting the multiple rates of return when comparing alternatives x = 2 and x = 3. Again, a simple plot of net present values versus interest rates for the incremental benefits and costs between alternatives x = 2 and x = 3 would have quickly resolved the problem. Figure 6 shows that plot and clearly demonstrates that the return from the increment in cost in moving from alternative x = 2 to x = 3 is acceptable (increases the net present value) only if the MARR or opportunity cost of capital is between 15.7 and 271 percent. For a MARR below 15.7 percent, alternative x = 2 is the best among the 3 alternatives, but, for a MARR between 15.7 and 271 percent, alternative x = 3 is the best among alternatives x = 2 and x = 3 although it is still unacceptable for a MARR greater than 21 percent. Also, for a MARR between 20.7 and 24 percent, alternative x = 1 is the best. But, without having this plot or other net present value computations in addition to the normal set of basic and incremental rates of return, the decisions among these 3 alternatives can only be ambiguous or wrong.

The ambiguities or inaccuracies among the alternatives noted in the examples not only can but often will result in a comparison of the benefit and cost streams for different alternatives. These examples, although they seem contrived, should not necessarily be regarded as atypical or trivial. They serve to emphasize in the strongest possible way that either ambiguous or wrong answers can occur when the internal rate of return method is stictly applied. However, when the net present value method is applied, in all cases (including those with different or equal initial costs and those with different terminal or replacement dates), answers will always be clear-cut and unambiguous.

The reasons for ambiguities occurring with the internal rate of return method have been discussed amply and thoroughly in both the economics and engineering economics literature (1, 2, 3, 4, 5). They hardly need much more than a brief discussion here. Problems arise because the internal rate of return method assumes that earnings or benefits accrued before the end of a project replacement date or planning period are reinvested at the internal rate of return rather than at the minimum attractive rate of return or opportunity cost of capital. This assumption hardly seems sensible because, by definition, MARR defines the return that other alternative investment opportunities will provide for funds that are released at any time during the period of analysis.

CONCLUDING REMARKS

Hopefully these examples and comments will prove that strict application of the internal rate of return method can lead to incorrect or ambiguous answers even if the special ordering technique suggested by Bergmann (6, p. 81) is applied.

Also it should be clear that the simplest and most unambiguous way to carry out benefit-cost analyses for mutually exclusive alternatives is merely to calculate the net present values for each of the alternatives over the entire range of relevant interest or discount rates. None of the iterations, multiple solutions, and complicated calculations of the internal rate of return method is required. Should the range of interest rates being considered be large, then numerous calculations may be required. Nonetheless, they are easily carried out, and the results can be plotted on a set of curves showing for each alternative the net present value versus the interest rate, or they can be displayed in tabular form. Such a set of curves, similar to those shown in Figure 5, or a table will indicate the alternative that has the highest positive net present value under certain interest rate conditions. The method is complete, avoids complications and ambiguities, and provides the maximum of benefit-cost information to the policy maker.

Finally, I emphasize the reality of the 3 examples and problems I have discussed. Admittedly, the numbers used in the 3 illustrations were hardly typical (they were contrived for computational ease) and the 2- and 3-year analysis periods were much too short to apply to the usual public project analysis. However, the ambiguities that did stem from these examples and the multiple solutions that did occur with the internal rate of return analysis method are realistic and not necessarily atypical. In fact, because of the long service lives of public projects and because of the almost certain probability that in some future years outlays will outweigh benefits, it appears that multiple solutions and ambiguities would be even more likely in actual project analysis than they were in the examples if one were to employ the rate of return method. This simply underscores the importance of rejecting the internal rate of return method in favor of the more certain and straightforward net present value method.

ACKNOWLEDGMENT

My appreciation is gratefully extended to Dietrich R. Bergmann for pointing out a serious error that appeared in an earlier version of this paper; substantial improvement of the paper resulted from his discovery. I do not burden him with any subsequent errors of fact or judgment to the extent there are any. I am also grateful for Gerald Kraft's earlier contributions, which improved the paper in important ways.

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DISCUSSION

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It is useful to clarify methodological ambiguities that exist in the literature. Therefore, Wohl is to be complimented on his effort to further identify and illustrate the difference between the rate of return method and net present worth method in comparing mutually exclusive investment alternatives.

Wohl's paper appears to be a reply to my Highway Research Record paper of 1973 (6). In that paper I indicated that many authors held in disrepute the rate of return method in comparing mutually exclusive alternatives for two reasons.

1. Where the solution for the rate of return is unique, rate of return methodology is alleged to occasionally yield a conclusion that is directly opposite to that produced by application of the net present worth method. This has often been alleged to be the case for alternatives with equal investments.
2. Where the solution for the rate of return is not unique, conclusions stemming from application of the rate of return method are ambiguous whereas those stemming from net present worth methodology are always unambiguous.

My 1973 paper (6) indicated that reason 1 is invalid. Illustrations that have been published to point out alleged inconsistencies between the 2 methods were examined and found to be devoid of any analysis of incremental cash flows, which is a fundamental step in comparing mutually exclusive alternatives by the rate of return methodology. Because most of those illustrations involved alternatives having identical initial investments, a detailed procedure was presented in that paper that showed exactly how to handle such cases. The reader will find that the procedure is a straightforward extension of the rate of return method for comparing mutually exclusive alternatives as it is already defined in standard textbooks on engineering and managerial economics.

With regard to reason 2, my paper (6), near the end, recognized the possibility of multiple solutions for rate of return and pointed out that, in fact, both methods are ambiguous in such cases. Furthermore, it was clearly pointed out that the algorithm presented in that paper reconciled problems dealing only with situations that other authors have categorized as being covered by reason 1.

Wohl's paper includes 3 examples, the first of which corresponds to the first example presented in my paper (6). He suggests that the logic I presented there does not apply to a period of analysis beyond 2 years. Such a suggestion is clearly without foundation.

In the review of his second example Wohl refers to the method summarized in my paper (6, p. 81) and asserts that it yields ambiguous conclusions. This assertion is without basis because the method summarized applies only to situations in which the rate of return is unique for the basic investment and the incremental investment. Each alternative presented in Wohl's second example involves not 1 but 2 solutions for the rate of return. With regard to the second example, it should be noted also that the approach Wohl uses to complete the analysis of the 2 alternatives by what he refers to as the "rate of return method" is one that I have not seen before.

The third example in Wohl's paper rather nicely illustrates a situation in which the rates of return are unique for basic investments but not unique for incremental investments. The procedure in my paper (6, p. 81) does not apply here for the same reason that it does not apply in Wohl's second example.

Close to the conclusion of his paper, Wohl suggests that the reader consult the literature (1, 2, 3, 4, 5) for further background and support of his viewpoints. A review of these references may be of interest to the reader. I suggest that the reader consult my paper (6) before drawing any conclusions from Wohl and Martin (1). Lorie and Savage (3, Table 2) apply both the rate of return and net present worth methods to the evaluation of 2 investment alternatives that are mutually exclusive from a capital budgeting perspective rather than a physical perspective. The reader will find that computation of the rate of return for the increment between the cash flows of the 2 alternatives will resolve the apparent inconsistency discussed there.

Solomon (2) deals with 2 illustrations, the first of which falls into the general category of situations covered by reason 1 and the second of which involves a situation covered by reason 2. With regard to his first example, straightforward application of the method introduced in my paper (6, p. 81) again results in a decision consistent with those given by the net present worth method and by both of the other 2 approaches that Solomon suggests as alternates to the rate of return method.

Bierman and Smidt (4) present results that I also have referenced (6).

Hirshleifer, DeHaven, and Milliman (5, Chapter 7, p. 167) compare net present worth and rate of return methods in situations covered by reason 2. Their illustration and claim (5, pp. 170 and 171) regarding the failure of the rate of return method involve reason 1. Note, though, that their claim is resolved by using the approach defined in my paper (6, p. 81).

From the foregoing review, it is readily apparent that the reason 1 illustrations cited by Wohl and his references are all resolved by applying the approach defined in my paper (6, p. 81). However, we have a different situation when encountering reason 2 situations; this is shown by Wohl's second and third examples. It is indeed appropriate to say that the rate of return method is not well defined and is ambiguous for such cases. It should be added, though, that the net present worth method, although always unambiguous in such cases, can be deceptive and misleading in its simplicity and straightforwardness. For instance, in Wohl's second example, blind adherence to the net present worth criterion would result in rejection of both alternatives if the MARR is 15 percent, and further consideration of each alternative if the MARR is increased to around 26 percent. It is a strange investment alternative whose total outlays exceed its total receipts and which becomes profitable only as the MARR increases. This point is not new; it has been made by Teichroew, Robichek, and Montalbano (7). Their treatment of the problems associated with both methods when the solution for the rate of return is not unique is extremely comprehensive and extends the contributions made by Solomon (2) and Lorie and Savage (3). I highly recommend the Teichroew, Robichek, and Montalbano (7) paper to readers seeking further perspective on situations involving multiple solutions for the rate of return.

ACKNOWLEDGMENT

The viewpoints expressed in this discussion are my own; they do not necessarily represent those of my employer nor any organization with which I am affiliated.

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AUTHOR'S CLOSURE

In many respects I do not think Bergmann's discussion is worthy of further comment. However, because the evaluation techniques in question are widely used and misused in practice and because Bergmann's paper (6) and discussion are both terribly misleading (the latter is even incorrect in some respects), I will respond to 4 aspects of his discussion.

1. In the third paragraph of his discussion, Bergmann says that reason 1 for rejecting the rate of return method is invalid. This, of course, is misleading. Specifically, correct results and decisions resulting from using the rate of return method (with equal initial costs and a unique solution) will necessarily result only if Bergmann's special ranking method (6, p. 81) is employed also. Because this ranking method is not an inherent feature of the rate of return method as widely discussed and employed, I can only regard his flat statement as misleading, if not inaccurate. For instance, if the data for alternatives 1 and 2 in example 1 and Table 1 of my paper are reversed and the commonly applied rate of return method (that without special ranking techniques, which Bergmann admits is an "extension of the rate of return method") is used, then the incorrect alternative will be selected even if the analysis of incremental cash flows is incorporated. I ask: How many engineering economists have ever heard of, much less understand, Bergmann's ranking technique, and how many practicing analysts understand that unique solutions do not always occur?

2. In the sixth paragraph of Bergmann's discussion, he states that I asserted that the method summarized in his paper (6, p. 81) yields ambiguous conclusions. He says that this is without basis because the method summarized by him applies only to situations in which the rate of return is unique for the basic investment and the incremental investment. First, the assertion is entirely correct. Second, I said (somewhat differently than implied by Bergmann) that the data in example 2 and Table 2 of my paper "will demonstrate the ambiguity that can result from using the internal rate of return method in the usual fashion even when alternatives are ranked in the manner outlined by Bergmann." I did not imply that Bergmann would find a different result; to do so would be inaccurate and misleading. In short, Bergmann's comment is without redeeming value.

3. In the eighth paragraph of Bergmann's discussion, he correctly notes that Wohl and Martin (1, section 8.7) failed to compute the rate of return for the increment between the cash flows of the 2 alternatives. This I freely acknowledge; I did so in the first paragraph of my paper. (It is worth noting, though, that this failure was not repeated when using the same data within example 1; this is a point that Bergmann overlooks.) However, once again, Bergmann is incorrect in saying that "the reader will find that computation of the rate of return for the increment between the cash flows of the 2 alternatives will resolve the apparent inconsistency." Although carrying out this additional computation is necessary, it is not sufficient. If you reverse the data for alternatives 1 and 2 in example 1 and Table 1 of my paper and only compute the rates of return for the alternatives and the incremental cash flows between the 2 alternatives, you will obtain an incorrect result. You must also rank the alternatives as Bergmann suggested. Thus, once again, Bergmann has misled the reader.

4. Bergmann, in the last paragraph of his discussion, comments on the applicability of the rate of return and net present worth methods to situations having multiple rates of return (nonunique solutions). In part, he said: "It is indeed appropriate to say that the rate of return method is not well defined and is ambiguous for such cases." For once, we can agree. But then he adds: "It should be added, though, that the net present worth method, although always unambiguous in such cases, can be deceptive and misleading in its simplicity and straightforwardness." Surely Bergmann is not serious. If the rate of return method is ambiguous and the net present worth is always unambiguous (and straightforward), then what better reason is there to reject the rate of return method outright? Also, why is an unambiguous and straightforward method deceptive and misleading? I take it that Bergmann feels that the net present worth method is deceptive and misleading because certain investment situations can result in negative net present worths if the discount or interest is 0. Although he says this is a strange investment alternative, he makes no effort to justify the comment. Consequently, because this situation can, and in all likelihood will, occur (because of heavy future expenditures relative to benefits, for example), Bergmann's comment must be dismissed, at least as a general proposition, because it has no basis in fact.

Bergmann's paper was entitled Evaluating Mutually Exclusive Investment Alternatives: Rate-of-Return Methodology Reconciled With Net Present Worth (6). After carefully reading my paper, as well as Bergmann's paper and discussion, it should be perfectly clear that the 2 methods can always be reconciled if and only if the rates of return for both the alternatives and incremental cash flows between alternatives are unique and if the alternatives are ordered in the fashion that Bergmann suggests (6, p. 81). Thus to imply as the title of Bergmann's paper does that the 2 evaluation alternatives can be reconciled for the general case is both misleading and deceptive. As a consequence, I wrote my paper and this closure to clarify this and other misconceptions.

SENSITIVITY ANALYSIS OF RATE OF RETURN

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The Oregon Department of Transportation recently completed a study of the rate of return method of evaluating highway projects. Sensitivity analysis, the most interesting feature of the research, derives from the flexibility of the computer program that was developed to facilitate the calculations. Most sensitivity analyses have tested the effects of varying the assumptions underlying road-user studies such as project life, discount rate, or terminal value. The Oregon program can analyze the sensitivity of variables such as speed, average daily traffic, and maintenance costs calculated for each project. Using the program, rates of return were computed for 66 projects and then recomputed with a number of specified changes in each of the major variables. Average errors and confidence intervals were calculated for every variable. Changes in some items such as right-of-way and construction costs, average daily traffic, value of time, and, especially, speed greatly affected rate of return. Increases or decreases in other factors such as vehicle operating cost and maintenance and operation cost had negligible effects. This study clearly shows that estimates of some factors need to be improved and that care should be exercised in using the results of highway economy studies. Until better estimates exist, the use of a range of values for a rate of return is more defensible than is specifying a particular number.

•RECENTLY, the Oregon Department of Transportation completed a study of the rate of return method of evaluating highway projects. The resulting report includes a discussion of the assumptions and values used in the calculations, a manual to guide analysts in gathering and organizing data, and a computer program that can be used to calculate both a rate of return and a benefit-cost ratio for highway projects. The research was intended to improve and standardize the methods applied in road-user analyses and to make decision makers aware of the strengths and limitations of highway economy studies.

Sensitivity analyses, the most interesting feature of the report, relate to the flexibility of the computer program. Most road-user calculations assume an increase in traffic throughout the life of a facility and apply a reduction in road-user costs to this flow of traffic. The Oregon program, however, allows the variables in the calculations to be changed in any year. If special circumstances exist that are expected to result in more traffic, fewer trucks, reduced speeds, lower maintenance costs, or other changes, then these can be considered explicitly in the computations. This characteristic is especially valuable when traffic increases toward the end of a project's life result in greater congestion, reduced speed, and lower road-user benefits.

With this program flexibility, one can test the sensitivity of the important assumptions and variables in rate of return calculations. To date, most sensitivity analyses have tested the effect of varying the assumptions underlying road-user studies. The assumptions include the life of a project, discount rate, and salvage value. Usually, these are tested by using a formula, not by studying computations of benefits and costs for actual projects. The Oregon computer program has the capability to analyze such items as speed, average daily traffic, and maintenance costs calculated for each project. The testing of these factors was facilitated by the need to evaluate a number of proposed projects to be considered for construction with funds from the sale of bonds. These prospective investments provided the opportunity to observe the effects of changes in variables in actual situations. Although the tests were conducted with rate of return computations, the results also apply to other kinds of road-user analyses.

SENSITIVITY ANALYSIS

The accuracy of the rate of return calculations is dependent on the accuracy of the input variables. It is recognized that values for all variables are estimated or measured with some degree of error. For each major variable, an analysis was undertaken to determine the sensitivity of the rate of return to errors of specified magnitudes. That is, if it is known that estimates of average daily traffic are generally accurate within a 10 percent range, then the effect of this magnitude of error can be calculated. A confidence interval for such a calculation indicates how the error can be expected to affect the rate of return. A 95 percent confidence interval, for example, would include the true rate of return 95 percent of the time. From these statistics, we can be relatively sure that imperfections or inaccuracies will affect the rate of return within prescribed limits. A short confidence interval for the rate of return when a particular variable is changed means that the rate of return is not sensitive to that input variable; an error in the variable would not be expected to affect the rate of return a great deal.

In this study, 95 prospective highway projects were reviewed. Of these projects, those that had a rate of return in a normal range were selected for sensitivity analysis; 66 projects having a rate of return between 0 and 25 percent were chosen. The exclusion of 29 projects with rates of return below 0 and above 25 percent should have made confidence intervals smaller than if all projects were analyzed.

The sensitivity analysis was conducted by changing a particular variable by a certain amount for all 66 projects. For example, the first change was to increase right-of-way and construction cost by 20 percent. Then, a new rate of return was calculated for each project with the specified change. The algebraic difference of the new rate of return minus the original rate of return was calculated for every project. These differences were used to compute confidence intervals. The average changes and confidence intervals for the rate of return calculation for the 66 projects are given in Table 1.

The data in Table 1 indicate that rate of return calculations are relatively sensitive to errors in estimates of right of way and construction costs, average daily traffic, value of time, and, especially, speed. Because, in estimating right-of-way and construction costs and average daily traffic, an error of 10 percent is considered acceptable, it is clear that rates of return must be interpreted carefully. An error of 10 percent for these variables suggests that, rather than stating a rate of return as 8 percent, for example, it should be expressed as a range of, for example, 7 to 9 percent. Judging from the confidence intervals, one can conclude that the limits in some cases should be broad. Because the value of time represents an assumption that can be applied only generally, even greater reason exists not to specify a particular rate of return.

The extreme sensitivity of speed suggests that, if the analyst does not have confidence in his or her computations, then he or she should not calculate a rate of return. The effects of errors of 10 percent or 5 mph (8 km/h) are so great that, if calculations are not more accurate than these levels, they are of dubious value.

It is interesting to note that, even with large differences in variables [such as a difference in speed of 5 mph (8 km/h)], the rank order of the 66 projects did not change appreciably. The correlation coefficient between the original ranking and new ranking after an assumed change in a variable was never less than 0.99.

For several variables, including vehicle operating cost, percentage of trucks, and maintenance and operations cost, sensitivity was slight enough so that errors were not of such great importance. It appears that efforts should be devoted to improving estimates of the other variables rather than these because their effect on rates of return will not be appreciable whether the items are exact or whether they are substantially in error.

Unfortunately, the analyst cannot be certain of the magnitude or direction of error

Table1. Sensitivity analysis for major rate-of-return variables.

Variable	Amount of Change	Avg Change in Rate of Return (percent)	95 Percent Confidence Interval[a] (percent)
Right-of-way and construction cost	+20 percent	-1.8	±4.8
	-20 percent	2.4	±4.8
	+10 percent	1.0	±2.2
	-10 percent	1.1	±2.2
	+5 percent	-0.5	±1.1
	-5 percent	0.5	±1.1
Average daily traffic	+20 percent	2.0	±4.4
	-20 percent	-2.2	±4.4
	+10 percent	1.0	±2.2
	-10 percent	-1.1	±2.2
	+5 percent	0.5	±1.1
	-5 percent	-0.5	±1.1
Value of time	+50 percent	1.4	±3.2
	-50 percent	-1.5	±3.2
Vehicle operating cost	+20 percent	0.1	±0.5
	-20 percent	-0.1	±0.5
Trucks	+20 percent	0.2	±0.4
	-20 percent	-0.2	±0.4
Proposed maintenance and operations	+20 percent	0.08	±0.2
	-20 percent	0.09	±0.2
	+10 percent	0.04	—
	-10 percent	0.04	—
Base maintenance and operations	+20 percent	0.06	±0.2
	-20 percent	-0.07	±0.2
	+10 percent	0.03	—
	-10 percent	-0.04	—
Base speed	+20 percent	-5.9	±16.9
	-20 percent	7.7	±16.9
	+10 percent	-2.5	±8.0
	-10 percent	3.8	±8.0
	+5 mph	-5.4	±15.5
	-5 mph	6.4	±15.5
	+2 mph	-2.5	±7.0
	-2 mph	2.4	±7.0
Proposed speed	+10 percent	1.7	±8.0
	-10 percent	-3.3	±8.0
	+5 mph	2.4	±8.2
	-5 mph	-3.4	±8.2
	+2 mph	1.1	±5.0
	-2 mph	-1.5	±5.0

Note: 1 mph = 1.6 km/h.

[a]The confidence interval shows the range within which we are confident that the true rate of return will fall 95 percent of the time. For example, if one of the 66 projects has an 8 percent rate of return, but we are only assured that we are within 20 percent of the actual right-of-way and construction cost, then it can only be stated that the true rate of return will fall between 3.2 and 12.8 percent 95 percent of the time.

in the estimates of many variables. If errors in the more sensitive variables tend to be self-canceling, then relatively more confidence can be placed in a rate-of-return solution. It is possible, however, that traffic, speed, and cost, for example, might all be estimated in a way that would cause the rate of return to be either overestimated or underestimated. This is a further reason to interpret a rate of return as representing a range rather than a single value.

CONCLUSIONS

It has been argued elsewhere that economic analysis often is not understood, frequently is misused, and should be used more with improved methods. Although this paper most likely will not cause a rush to apply road-user analyses more often, it should contribute to their more intelligent application.

It is clear from this study that estimates of some variables need to be improved and that care should be exercised in using the results of highway economy studies. It appears that a rate of return or benefit-cost ratio is best used as 1 indication of a project's merit. A deficiency or sufficiency index, accident rating, and surface condition rating and an environmental assessment also should be used. A rate of return will be relatively more important for some investments than for others. As estimates are improved, the kinds of projects to which road-user analyses can be applied successfully will increase. At best, however, it seems that the use of a range of rates of return would be more defensible than would using a particular number.

In the future, if the rate of return program is going to be as useful as possible, more work will have to be done on (a) improving the estimates of the values for variables that substantially influence the rate of return; (b) generalizing the approach for applying the program, for example, to safety projects and maintenance programs; and (c) combining rate of return results with those of a deficiency index and with accident information for interpreting project evaluation techniques for decision makers.

Notwithstanding the problems described in this paper, a highway agency should be capable of producing a rate of return evaluation for its investments. The method described in this paper represents a significant contribution to project selection methodology.

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