SPECIAL REPORT HRB

92

EVALUATION OF MUTUALLY EXCLUSIVE DESIGN PROJECTS

HIGHWAY RESEARCH BOARD

NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES
NATIONAL ACADEMY OF ENGINEERING

HIGHWAY RESEARCH BOARD

2101 Constitution Avenue Washington, D. C. 20418

SPECIAL REPORT 92

EVALUATION OF MUTUALLY EXCLUSIVE DESIGN PROJECTS

MARTIN WOHL, *University of California, Berkeley*

BRIAN V. MARTIN, *Greater London Council, London, England*

Subject Area

81 Urban Transportation Administration
84 Urban Transportation Systems
15 Transportation Economics

HIGHWAY RESEARCH BOARD

DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

Washington, D.C., 1967 Publication 1446

Department of Urban Transportation Planning

Pyke Johnson, Chairman
Washington, D. C.

HIGHWAY RESEARCH BOARD STAFF

J. A. Scott, Urban Transportation Planning Specialist

Frank N. Barker, Assistant Chief Engineer—System Atchison, Topeka and Santa Fe Railway Company, Chicago, Illinois
Fred J. Benson, Dean, College of Engineering, Texas A and M University, College Station
Donald S. Berry, Chairman, Department of Civil Engineering, The Technological Institute, Northwestern University, Evanston, Illinois
W. J. Burmeister, State Highway Engineer, State Highway Commission of Wisconsin, Madison
E. Wilson Campbell, Director, Chicago Area Transportation Study, Chicago, Illinois
J. Douglas Carroll, Jr., Executive Director, Tri-State Transportation Committee, New York, N.Y.
F. Stuart Chapin, Jr., Research Director, Center for Urban and Regional Studies, University of North Carolina, Chapel Hill
John J. Cummins, Manager, Highway Department, Automobile Manufacturers Association, Detroit, Michigan
Harmer E. Davis, Director, Institute of Transportation and Traffic Engineering, University of California, Richmond
Alfred Eisenpreis, Vice President, Allied Stores Corporation, New York, N.Y.
Wesley E. Gilbertson, Chief, Division of Environmental Engineering and Food Protection, Public Health Service, U.S. Department of Health, Education and Welfare, Washington, D.C.
John R. Hamburg, Creighton Hamburg, Inc., Delmar, New York
Robert L. Hardin, Jr., General Manager, Transportation Marketing, United States Steel Corporation, Pittsburgh, Pennsylvania
Frederick O. Hayes, Director, Bureau of the Budget, New York, N.Y.
Patrick Healy, Jr., Executive Director, National League of Cities, Washington, D.C.
Bernard F. Hillenbrand, Executive Director, The National Association of Counties, Washington, D.C.
E. H. Holmes, Director of Planning, U.S. Bureau of Public Roads, Washington, D.C.
Edgar M. Horwood, Professor of Civil Engineering, University of Washington, Seattle
John T. Howard, Head, Department of City and Regional Planning, Massachusetts Institute of Technology, Cambridge
Fred W. Hurd, Director, Bureau of Highway Traffic, Yale University, New Haven, Connecticut
Richard Ives, Director, Division of Planning Assistants, Office of the Assistant Secretary for Metropolitan Development, Urban Renewal Administration, U.S. Department of Housing and Urban Development, Washington, D.C.
A. E. Johnson, Executive Secretary, American Association of State Highway Officials, Washington, D.C.
J. E. Johnston, Deputy Director of Highways, Planning and Traffic, Utah State Department of Highways, Salt Lake City
Burton W. Marsh, Executive Director, AAA Foundation for Traffic Safety, Washington, D.C.
Robert E. McCabe, Assistant Commissioner for Field Operations, U.S. Department of Housing and Urban Development, Urban Renewal Administration, Washington, D.C.
J. B. McMorran, Superintendent, New York State Department of Public Works, Albany

William L. Mertz, Technical Director, Tri-State Transportation Committee, New York, N.Y.
Charles L. Miller, Head, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge
Robert B. Mitchell, Chairman, Department of City and Regional Planning, Institute for Urban Studies, University of Pennsylvania, Philadelphia
Walter S. Rainville, Jr., Director of Research, American Transit Association, Washington, D.C.
Clifford F. Rassweiler, President, Rassweiler Consultants, Inc., Short Hills, New Jersey
Carlton C. Robinson, Director, Traffic Engineering Division, Automotive Safety Foundation, Washington, D.C.
Carl C. Saal, Deputy Director, Office of Research and Development, U.S. Bureau of Public Roads, Washington, D.C.
Merlin Smelker, Director of Public Improvements and Urban Transportation Studies, Office of Program Policy, Department of Housing and Urban Development, Washington, D.C.
Wilber E. Smith, Executive Director, Southern California Association of Governments, Los Angeles
F. Houston Wynn, Wilbur Smith and Associates, New Haven, Connecticut
Charles J. Zwick, Assistant Director, Bureau of the Budget, Washington, D.C.

COMMITTEE ON TRANSPORTATION SYSTEM EVALUATION

(As of December 31, 1966)

William L. Mertz, Chairman
Technical Director
Tri-State Transportation Committee
New York, N.Y.

Joseph W. Hess, Secretary
Highway Research Engineer
U.S. Bureau of Public Roads, Washington, D.C.

Frank E. Barker, Supervisor, Traffic Planning, Chicago Transit Authority, Chicago, Illinois
Donald S. Berry, Chairman, Department of Civil Engineering, The Technological Institute, Northwestern University, Evanston, Illinois
E. Farnsworth Bisbee, Associate Professor of Civil Engineering, Massachusetts Institute of Technology, Cambridge
E. Wilson Campbell, Director, Chicago Area Transportation Study, Chicago, Illinois
Arthur A. Carter, Jr., Principal Research Engineer, Traffic Systems Division, Office of Research and Development, U.S. Bureau of Public Roads, Washington, D.C.
George A. Ferguson, Southeastern Pennsylvania Regional Planning Association, Pittsburgh
Frank W. Herring, Deputy Director for Transportation Policy, Port Development Department, The Port of New York Authority, New York, N.Y.
Neal A. Irwin, Executive Vice President, Traffic Research Corporation, Toronto, Ontario, Canada
Paul W. Shuldiner, Consultant to the Director, Office of High Speed Ground Transportation, Transportation Systems Planning Division, U.S. Department of Commerce, Washington, D.C.
Edward Sullivan, Tri-State Transportation Committee, New York, N.Y.
Edwin Thomas, Research Director, The Transportation Center, Northwestern University, Evanston, Illinois

Robert S. Vogt, Chief, Transportation and Planning Section, Vogt, Ivers and Associates, Cincinnati, Ohio

Martin Wohl, National Science Foundation Fellow, University of California, Berkeley

F. Houston Wynn, Associate, Wilbur Smith and Associates, New Haven, Connecticut

Charles J. Zwick, Assistant Director, Bureau of the Budget, Executive Office Building, Washington, D. C.

PREFACE

This report merely serves to introduce the subject of system evaluation. The first chapter establishes the framework for evaluating alternative engineering designs and defines the major aspects of analysis which affect system evaluation; further, emphasis is placed on policy and judgmental issues and on system interactions which can significantly affect the measurement and level of system or project benefits and costs.

The second chapter describes and compares four of the principal techniques of economic analysis and evaluation; this treatment, while complete, deals only with the problem of evaluating mutually exclusive alternatives. In the third chapter, three alternative highway projects have been analyzed and evaluated in order to determine their economic feasibility, both in an absolute and relative sense. The major focus of the example (Chapter Three) is a demonstration of the application of various economic analysis techniques and a detailing of the requisite information for their use. Every attempt was made to render the example problem realistic and to include all relevant aspects; while the actual data used, and the assumptions made about unit costs and demand relationships, were chosen in this sense, we should point out that it is not their validity which is the subject of attention, but rather their analysis which is primarily of concern.

Also, we would note that this material has been prepared as part of a more comprehensive traffic system planning text and thus serves to demonstrate use of principles which were outlined in other parts of that text.

Finally, we gratefully acknowledge the guidance and assistance of John R. Meyer and Gerald Kraft, though we do not burden them with responsibility for any of the weaknesses of this textural material or imply agreement with our conclusions on their part.

M W and B V M

Contents

CHAPTER ONE

A Framework for Evaluating Alternative Engineering Designs

1.1 INTRODUCTION

Historically, engineering education and practice has concerned itself more with the technological capabilities of physical systems and with the geometric design or layout of these physical systems than with the process of deciding whether any system should be built, and if so which system is best. Increasingly, though, engineers and designers are becoming familiar with and taking advantage of economic analysis and decision-theory techniques. Rather than serving as a panacea for poor engineering design, these techniques simply aid the engineer in developing more creative and analytical design abilities. Further, they assist the designer and engineer in seeking the best use of technological resources for social purposes and in assuring that the relevant questions are asked at each stage of his search-design-analyze process.

At the outset, it should be emphasized that the material in this and the following two chapters represents only an introduction to the subjects of economic analysis and capital budgeting and cannot be regarded as a substitute for a more comprehensive, complete and rigorous treatment. Nevertheless, these notes should provide the engineer with a preliminary understanding of the role of economic analysis and its relevance to traffic engineering. The traffic engineer will also have a better understanding of the kind and nature of traffic engineering data requisite to economy studies, and he will have a better grasp of the way in which economic analysis can enhance his creative engineering design talents.

Finally, it is emphasized that this introductory treatment is intended to deal primarily with the more usual highway or traffic design situation wherein the engineer's task is to propose and evaluate alternative physical designs for achieving roughly the same objective (i.e., he is choosing among a set of mutually exclusive designs or design features). Subjects concerning highway programming, particularly where budget constraints may affect the program to be selected, and highway program management while far from being unimportant are not discussed. Nor does the material herein consider certain important social and political matters (such as income distribution effects, appropriate pricing policies, or other equity matters) even though they may significantly affect and alter the travel demand and project costs and benefits.

1.2 PURPOSE OF ECONOMIC ANALYSIS AND MAJOR CONSIDERATIONS

The principal use of economic analysis by highway and traffic engineers is to provide an approach to answering the fundamental question: Is the proposed project worthwhile and does it represent the "best" use of the associated resources? Stated in this fashion, it should be evident that our discussion will be restricted to mutually exclusive alternatives (i.e., while several alternative designs will be considered, including the null or do-nothing alternative, only one of the alternatives will be undertaken) and will not extend to the more general situation involving selection of the best investment program or group of projects.

1.2.1 Point of View, or "Worthwhile" to Whom?

While the engineering literature often suggests that the techniques for making an appropriate choice among mutually exclusive alternative projects are straightforward and simple, it is important to recognize that such is hardly the case. In fact, even to establish the basis for evaluating alternatives—that is, to state what is meant by "worthwhile" and "best" and what factors and elements one includes or excludes—is a most complex and sometimes judgmental procedure.

In deciding whether or not to make specific purchases, individuals continually are evaluating and weighing the alternatives and are called upon to decide whether it is worthwhile to use their (limited) available funds and resources in one way or another, or to withhold their use until some future time. Presumably, in making each decision the individual allocates his total resources in a fashion most "worthwhile" to him. On a larger scale, a private industrial firm operates in a similar fashion but considers each alternative use of its resources from its own "point of view" or in terms of the most "worthwhile" or profitable investment to its owners.

Importantly, as the individual or group of individuals making investments changes, a shift in point of view is generally to be expected and thus the final decision may change accordingly.

The problem of specifying whose interests are at stake, or to whom the investment is worthwhile, is more complex when public projects are considered. For example, should a state highway agency, in deciding among various highway projects (including the null alternative), consider only the consequences to the state highway users or those to the entire state populace or should it adopt a broader national point of view? Also, should the state highway agency consider the economic feasibility of only the state expenditures on construction, maintenance and administration or should it be concerned with the feasibility of the total outlays, whether state, federal, or local?

The arguments for and against different viewpoints are numerous. E. L. Grant persuasively argues that the economy of public works proposals (whether city, county, or state) "ideally, perhaps," should be considered from the point of view of all of the people in the country.[1] Kuhn takes what at first glance appears to be a stronger stand in noting:[2]

> Any public body should, logically, adopt the viewpoint of the economy as a whole. The very term public (authority, or agency, or enterprise) implies responsibility extending over the community at large. Indeed, "promotion and protection of the public interest," or similar principles, are by law supposed to guide the conduct of public bodies. Perhaps even more compellingly, public enterprise agencies are creatures of legislatures and through them answerable to the community. Indeed, under common law all business is public; only an arbitrary distinction separates private and public business. The distinction is suspended when "private" businesses, such as power, gas, telephone and telegraph companies, are regulated "in the public interest." That public enterprise should adopt a public viewpoint appears, then, to be self-evident. The point is salient: it has significant practical implications and invokes basic principles. It dictates that normally no costs or gains in public enterprise can be classified as external and disregarded.

While in the above paragraph Kuhn makes no distinction between local, state, or federal (public) agencies, and thus implies that all public agencies (whether local, state, or federal) should take the national economy viewpoint, the manner in which he distinguishes between and treats internal and external costs and gains (benefits) elsewhere

---

[1]E. L. Grant and W. G. Ireson, Principles of Engineering Economy, Ronald Press, New York, 1960, p. 445-456.

[2]T. E. Kuhn, Public Enterprise Economics and Transport Problems, University of California Press, 1962, p. 13. Earlier, on p. 8, Kuhn noted, definitionally, that "external values can be defined as signals not received by the decision maker but by other parties, and internal values as effects that are of definite concern to him."

in his text does suggest that at times he feels it is proper for a public agency to view only the costs and benefits to its own economy. This implication which we attribute to Kuhn is supported by his metropolitan transport example wherein intergovernment transfers are treated as benefits.[3]

An alternative position might be to consider the feasibility from the point of view of those whose funds are being risked. That is, the feasibility might be judged in terms of the welfare of those who must bear the burden of financing capital investments or future operating expenses should the expected benefits not materialize. This would appear to be the position of Richard Zettel, who noted:[4]

> The appropriate objective is to maximize benefits to the users who are called upon to finance the programme. . . . In some circumstances. . . it may be appropriate to seek contributions from the general treasury to finance that portion of the project which is justified on the grounds of general (rather than user) benefits.

Thus, with a pay-as-you-go or fully self-financed highway user tax financing program, only the user's viewpoint would appear to be relevant. However, should the highway program be financed out of general state or federal funds (or should highway bonds be floated and backed by the full faith and credit of the state or federal government), then the viewpoint of the entire state or federal populace would be appropriate. In general, to take the point of view of those whose funds are being risked will result in taking a "total public viewpoint," but the definition does permit a more restrictive position to be taken where it is appropriate (such as with privately financed toll facilities or with public facilities supported entirely through user tax revenues).[5]

1.2.2 Worthwhile in What Terms?

Another important aspect of economic analysis is the establishment of the yardsticks, or measures, by which the worthwhileness or feasibility of a project can be judged. Moreover, it is our view that worthwhileness should be defined from the point of view of the "owners" or those whose funds are being risked.

An answer to the question, "Worthwhile in what terms?," has three parts:

1. What specific factors or elements that are affected by the project do the "owners" (i.e., those whose funds are being risked) feel are of importance and of concern; these are the items of "cost" or "benefit";
2. What is the relative importance or relative value which the owners attach to the particular items of cost or benefit (i.e., what is the weight-scale by which the cost and benefit items can be placed on a commensurate scale); and
3. What are the constraints (if any) which the owners place on the system and which will or may affect the decision-making outcome.[6]

---

[3]Ibid., Table 2 and p. 55-66.

[4]Richard Zettel, Highway Benefit and Cost Analysis as an Aid to Investment Decision, Reprint No. 49, Institute of Transportation and Traffic Engineering, University of California.

[5]By contrast, the Doyle Report emphatically concluded that, "In consonance with the basic objective of Federal policy, governmental actions at all levels should be taken in the national public interest. Conflicting interest must, of necessity, yield to the greater good of all." [Emphasis added.] (From National Transportation Policy, Report for U.S. Senate Committee on Interstate and Foreign Commerce, U.S. Government Printing Office, Washington, D.C., Jan. 1961.)

[6]Rather than include some arbitrary objective alongside the other terms and give it some relative scale value, the owners may prefer merely to maximize their net benefit, for example, subject to some specified condition. In a sense, this specification would be somewhat analogous to certain types of government regulation, and is directly akin to establishing certain social objectives regardless of the impacts. While these constraints, or social objectives, will not directly enter the economic analysis, their economic consequences should be accounted for in the overall decision-making process; the economic value of social objectives can at least be determined by imputation, for example.

It should be evident that such a task for private projects is distinctly simpler and more straightforward than for public programs. Generally, costs for private projects include money outlays which must be made to obtain the capital, labor and service inputs, or to compensate others for damages of one sort or another; the benefits include the money revenues (or other types of payment) received as a result of the project investment.[7] In general, only items which in some way are actually translated into money terms are included in the economic analysis.

For the case of public projects at the federal level, all factors or elements of concern which have value to the owning public and for which value the public would willingly pay to gain, or to keep from losing, will be included. Thus commonly thought of social and political objectives can meaningfully be included in an economy study, provided of course that the owning public would be willing to pay for such or at least to trade-off some other object of interest or value where conflicts occur.[8] Generally, then, social or political factors enter the analysis only in those instances where society would be willing to forego dollar and cent or other marketable values in their stead. This assumption is made, first, since most tangible and so-called intangible objects of concern have a history of experience and have been valued at the marketplace (at least implicitly); thus we have a place to start in establishing relative if not absolute value scales (a problem that simply cannot be ignored one way or another). Second, this assumption is made to point out that factors of presumed concern to the owning public and for which they are not willing to forego something else of value (which must be foregone to achieve the object of concern) are just that—presumed rather than real. Third, and importantly, it is made in order to permit more reasonable comparisons among investments in the private and public sectors of the economy.

By this discussion, it is not implied that decisions involving other non-marketable political or social values are improper or avoidable. Rather, it is to emphasize that decisions to expend additional resources in order to meet or achieve some higher social goal or objective imply at least a limiting value of the social ends (since the extra costs could have been avoided by sacrificing the social objective). Also, the earlier remarks were intended to emphasize that lack of willingness to pay for some social objective (or at least to forego something else of value in order to achieve that goal) suggests the lack of real value associated with the objective. In any case, the engineer bears the responsibility of defining and quantifying (directly or by imputation) as many of these aspects as possible.

1.2.3 Definition of Costs and Benefits for Public Transport Projects

To state specifically what factors are relevant for economic analysis of broad-scale public projects one must ask what factors of concern are affected by facility investments (or by changes in facility operation, etc.). Principally, improvements to the transport system can change travel characteristics in terms of the amount of trip-making, its distributional (O-D) or time patterns, the people involved in the tripmaking, and the "cost" or service quality of the trip. In addition, changes can occur in the capital, labor and service requirements for designing, building, and operating the physical transport facilities and vehicles. Viewing these consequences from a broad public standpoint, the "costs" and "benefits" may be categorized as in Table 1.1.

The costs and benefits (Table 1.1) should be regarded as total system effects, or as the total costs incurred for and benefits accruing to the public at large from any specific alternative transport system; these total costs are in contrast to the additional or incremental costs or benefits stemming from an increment of investment, which can be determined directly from an analysis of the differences in total cost and

---

[7] In some cases, this narrow description will not be all inclusive.

[8] This position will be qualified in a later section in order to preserve comparability between private and public investment policy.

TABLE 1.1

TRANSPORT SYSTEM COSTS AND BENEFITS FOR PUBLIC PROJECTS*

A. Potential Costs Associated with Transport System

1. Facility construction and land acquisition costs
2. Dislocation and other social costs
3. Facility operation, maintenance and administration costs
4. User travel costs, to include:
   a. Vehicle ownership costs (excluding all fees and taxes levied to recover facility costs)
   b. Vehicle operating and maintenance costs (excluding all tolls and taxes levied to recover facility costs)
   c. Time costs
   d. Discomfort costs
   e. Inconvenience costs
5. Accident costs (to include costs of injury to all persons and property involved in vehicular accidents)
6. Terminal (parking) facilities costs

B. Potential Benefits Associated with Transport System

1. User travel benefits, to include:
   a. Perceived user travel benefits
   b. Non-perceived user travel benefits
2. Facility associated non-user revenues (such as concession revenues or property taxes)
3. Intergovernmental transfers (in those cases where other than a broad national viewpoint is taken)

*A broad point of view is intended for this listing; the interest and welfare of the entire nation is of concern. Definitionally, costs are meant to include all those efforts, sacrifices, losses, outgoes and expenses (whether or not they are compensated), and benefits are meant to include all money and non-money revenues, income, rewards, proceeds and values which result from the system and its usage. These definitions are closely related to those of Kuhn, op. cit., p. 31. However, it should be noted that all transferred benefits and multiplier effects are excluded.

benefit in moving to successively higher levels of investment. As will be shown, both types of information (that is, both the total and incremental values) are necessary to answer adequately the two questions:

1. Is the entire project worthwhile?
2. Is any additional improvement and investment worthwhile?

Nevertheless, the data which are gathered or forecast by the engineer for use in economic analyses will generally conform to total rather than incremental cost and benefit tabulations and thus is presented in that fashion at this stage of the analysis.

Table 1.1 differs substantially from tables often appearing in highway engineering economy studies and thus bears some explanation. First, a broad public viewpoint is adopted and, as a consequence, the general public may be regarded as the owners and as those whose costs and benefits are at stake. It follows, therefore, that costs or benefits to any subset of the public at large, however large or small the group, should be included in the tabulation and accounting.

Three other points are worth noting. One, while the decision-making agencies (such as the highway departments) hold the responsibility for committing public funds, they nevertheless can not be regarded as "owners" but should be viewed only as representatives of those from whom the funds are derived. Two, any commitment or forfeiture of resources, expense, time and effort resulting from the facility for which any member of the general public would willingly trade-off something else of value to avoid the loss or commitment should be included as a cost. Conversely, any revenues, proceeds or desirable experiences achieved as a result of the facility (and for which some member of the general public would willingly pay or tradeoff something else in value in order to achieve) should be included as benefit. Third, certain subsets of the general public will find their interests represented in the tabulation in more than one fashion.

For example, users of the facility are in the first instance concerned as owners of the facility and as they are at least partially responsible for the costs of facility construction, maintenance and administration. In the second instance, they are concerned as users of the facility who experience money, time, discomfort and inconvenience costs in the course of traveling and who simultaneously achieve certain benefits from tripmaking. Also, one subset of the general public may experience certain social costs (such as those associated with air pollution) which stem from travel made by another subset. Or, dislocated residents (either homeowners or renters) and disrupted community inhabitants may experience what might be termed social dislocation costs as a result of facility construction undertaken for the benefit of another subset of the general public. As a third example, accident costs may be incurred by three groups or subsets of the general public: owners and occupants of vehicles involved in accidents, owners of non-vehicular property damaged in accidents, and non-vehicular persons involved in accidents.

In Table 1.1 all items of cost are listed, whether or not the parties involved are compensated for the costs. However, certain payments (such as user taxes, fees and the like) which are made by users to recover certain items of cost and which do not represent an expenditure of resources are excluded from the cost tabulation; for example, to include both roadway costs and user tax payments as costs would result in double counting, and to include user payments instead of roadway costs would result in an improper cost accounting unless the roadway costs and user payments happen to be identical (and thus user payments could serve as a proxy for roadway costs).

These definitions and tabulation categories do not imply that either the money payments or other benefits for a particular item necessarily cover the costs to the general public for providing that item. For example, the user tax payments which are made to recover roadway costs may or may not actually cover the full costs of providing those facilities (interest included); similarly, accident insurance premiums or parking fees may or may not cover the full costs of accidents or terminal facilities. Problems of balancing costs and benefits, and of insuring that those for whom the costs are incurred pay those costs, far from being unimportant, are not discussed in this introductory treatment. In short, considerations of who should pay and who does pay the costs are disregarded at this stage; here, the only concern is what are the costs and what are the benefits, without regard for their incidence.

Within the benefit listing (part B, Table 1.1) intergovernmental transfers are included for those situations where a lower order government agency is conducting the analysis and chooses not to take a broader national point of view. Also, non-user benefits (both secondary and multiplier effects) were excluded from the listing, because of the possibility of double-counting (transferred benefits, and the like) and because of the possibility of rendering the analysis incomparable with those for investments in the private sector of the economy.[9]

---

[9]Aside from the difficulty of measuring such benefit aspects, it is important to insure comparability between public and private economic analyses, the latter of which seldom include such benefits (even when studied by governmental agencies). This point is well covered on p. 38-39 of H. Mohring and M. Harwitz, Highway Benefits—An Analytical Framework, Northwestern University Press, 1962. The subject of non-user effects and impacts has been widely discussed; for an introductory treatment see: A. L. Lang and Martin Wohl, Evaluation of Highway Impact, HRB Bulletin 268, 1960, p. 105 ff.

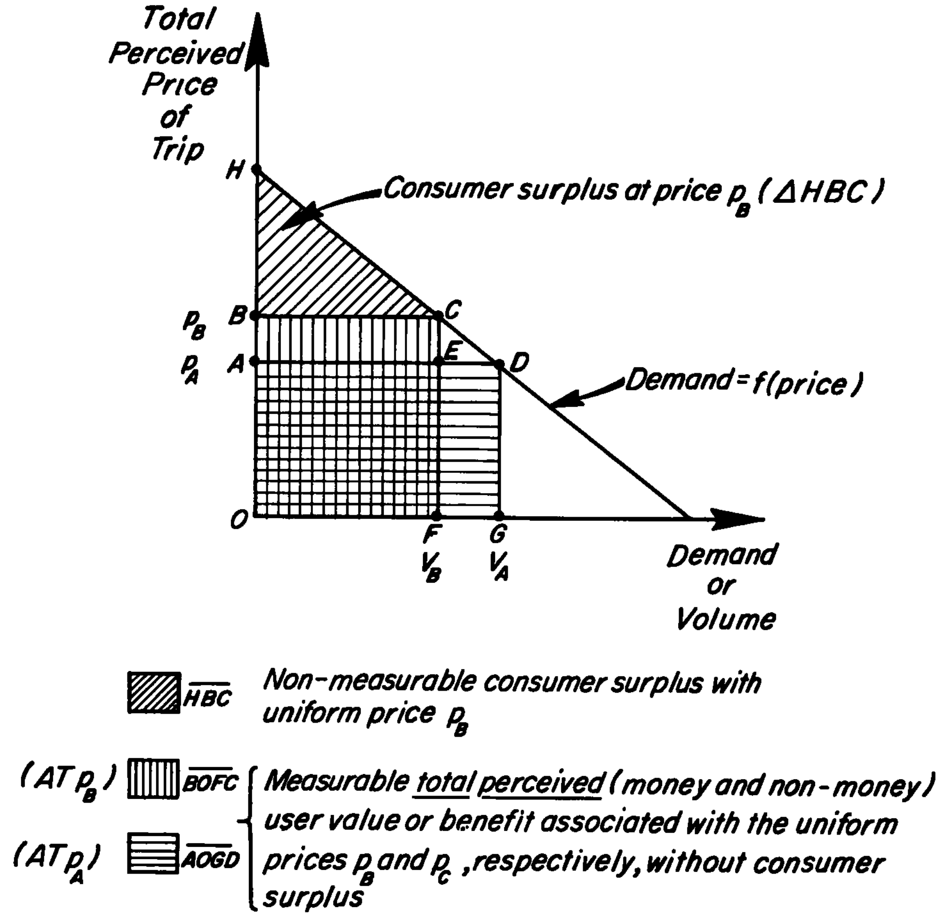

Figure 1.1. Demand curve showing benefit considerations.

A more detailed discussion of the benefit item "perceived user travel benefit" will be helpful; for this purpose, it is necessary to introduce demand function concepts. A demand function or demand curve is a statement of the number of trips which will be made or "purchased" at different levels of overall trip price, where the perceived price of travel is the total payment in expense, time and effort that the traveler perceives or thinks about in making a trip. The distinction between perceived payment and actual payment is essential; the former is appropriate in this instance since the demand curve (or demand relationships) is used to forecast travel, in which case the analysis must be made on the same basis as that which serves to motivate the traveler in making a decision to travel or not and in choosing among alternative modes, routes, destinations or times-of-day.

Figure 1.1 illustrates a demand curve for tripmaking between, say, a given set of origin and destination points, and for a specific time of day or common set of trip purposes.[10] Different people among those wanting to make trips between these points will value the trip differently simply because of differences in income and ability to pay for the trip, or because of differences in the urgency of the trip or in the value of getting to their destination, and so forth; in general, the demand curve will be downward

[10]The demand curve holds for a given level of income, population, and land-use distribution, etc. The demand is not necessarily (and probably is not) linear but is shown in that form for simplicity.

sloping.[11] In other terms, as the price of travel or as congestion increases less trips will be made, everything else being equal, and if the price or congestion is reduced more trips will be made.

Correspondingly, the demand schedule may be interpreted and used to indicate the willingness to pay for travel and thus to provide measures of the value or benefit associated with particular trips. However, some distinctions are necessary with regard to the latter point. For one, we must distinguish between what tripmakers actually do "pay" and their willingness to pay. By setting the price at level p_B (see Figure 1.1) and finding that V_B trips would be made, the value of the trip for the tripmaker at the "margin" can be determined; that is, the last person to purchase the trip just broke even, paying exactly as much as the trip was worth to him.[12] Obviously, this same value also serves as a measure of the amount each traveler does pay, as distinct from the total amount he would be willing to pay. No more than V_B trips would be made because the fixed price (p_B) is higher to those not making the trip than its value to them; thus, for price p_B those not making the trip would find that their position on the demand schedule is to the right of and below point C.

At this point, it is important to distinguish more precisely between "benefit" (and "user cost") as practiced by the highway engineer and those definitions used in this text. These distinctions are key to a full understanding of all that follows.

First, the economist defines benefit as being equivalent to value and thus it is equal to the gross amount that travelers would be willing to pay for a trip.[13] Referring to Figure 1.1, if the price were at a level p_B, travelers would be willing to pay amounts as indicated by the demand curve to the left of point C; or, to put it another way, if the price were p_B, then the total benefit or value accruing to the V_B tripmakers would be equal to area HOFC or the entire area under the demand curve and to the left of point C. If the price were lowered to p_A, then the total benefit or value accruing to V_A tripmakers would be equal to area HOGD.

Second, the highway engineer's definition of benefit does not correspond to the economist's definition but is usually defined as the reduction in user cost that accompanies a price change (where price is construed broadly in terms of the time, effort and expense of travel). In this example, if the price were at a level of p_B, then the cost to each user would be the same as the price he pays or p_B. (Of course, all but the tripmaker at the margin would be willing to pay more than that amount.) If the price were dropped to p_A, then the user cost would drop accordingly. The difference in "user cost," or reduction from p_B to p_A, is what the engineer usually defines as "benefit." Thus, the total amount of user cost reduction or total amount of benefit associated with a price reduction from p_B to p_A—as usually defined by the highway engineer—would be equal to the area BADC.

However, throughout this text the economist's definition of benefit will be adopted. The highway engineer's definition and use of the term benefit will be discarded as it is appropriate only for determining what is really the change in net benefit between pairs of alternatives but not including the null or do nothing case;[14] thus, the highway engineer's restricted definition of benefit is only appropriate for answering the question, Which way is best? It does not lend itself to answering the question, Why do it at all?

---

[11] Traditionally, the independent and dependent variable axes are reversed for the demand curve; the dependent variable is shown on the x-axis and the independent variable on the y-axis.

[12] A uniform single price has been assumed, and matters concerning heterogeneity and interpersonal comparisons are largely ignored.

[13] This is not to say, however, that all of this gross benefit should be included in the totals used to justify public investments; this is, in part, a matter of judgment and will be discussed later in the section.

[14] That is, in cases where there is an existing facility, the engineer's definitions will not permit examination of the overall feasibility of the existing facility (and thus of the possibility of abandoning the facility altogether). Nor does the engineer's definitions permit examination of the overall feasibility of the lowest cost alternative where no facility is yet in existence. More will be said about this topic in a later section.

For all tripmakers other than the one at the margin, it is reasonable to expect that some value or benefit over and above the price they must pay would be accrued. In the terms of the economist, all tripmakers or consumers except the traveler at the margin would accrue a surplus or "consumer surplus."

The additional value or benefit (over and above the price paid), which is termed consumer surplus by the economist, is not unique to public projects, but will generally be manifested in any private or public situation and with the same result. An individual will usually be willing to pay a little more than he was actually charged (or than his payments in time, effort and expense) and thus will receive a little extra value or net benefit. With a uniform, single-price policy, this surplus to the consumers would not be relevant to the economic analysis of a private firm since it does not represent revenue or benefit to the firm or its owners, but accrues only to its customers. Importantly, if consumer surplus is not considered and is not included in analyzing the economy of private investments, then to include it in those for the public sector would mean that expenditures could more easily be justified in the public sector.

In theory, consumer surplus is just as viable or not, beneficial or not, determinable or not, and thus includable or not in private as in public projects. Thus, we would argue that to compare the economic value of alternative uses of resources properly, a consistent practice should be followed in both private and public ventures. Furthermore, there is considerable doubt among economists as to the existence and measurement of the upper regions of the demand curve; thus far consumer surplus (in total) has been difficult if not impossible to measure and as a consequence can be regarded as indeterminate.[15]

Because of the incomparability that would result between public and private sectors of the economy, the latter of which does not include consumer surplus in the assessment of alternative investments, and because of the indeterminate nature of consumer surplus measurement, 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.

Some economists would appear to take issue with this position. Mohring, for example, specifically deals with the definition and measurement of consumer surplus but does not directly confront the issue in his book,[16] thus suggesting that consumer surplus can be included in a public economy study; Kuhn while noting both sides of the issue clearly feels that consumer surplus can be considered as net benefit allowable in the analysis.[17] Similarly, work conducted in England by Reynolds[18] and by Foster and Beesley advocates the inclusion of all user benefits, measurable or not and paid or not; in particular, Foster and Beesley note:[19]

> Road investment is beginning to be decided by calculation of consumers' rates of return by estimating the social benefits and costs incurred by building a new road. It seems sensible to treat urban rail investment similarly: which is what we have done for a particular investment in this paper.

---

[15] An important reference on the subject of consumer surplus is: I. M. D. Little, A Critique of Welfare Economics, Oxford Univ. Press, 1958.

[16] H. Mohring, op. cit., Chapter I and Appendix I, particularly.

[17] Tillo Kuhn, op. cit., Chapter IV.

[18] D. J. Reynolds, The Assessment of Priority for Road Improvements, Road Research Technical Paper No. 48, Road Research Laboratory, London, 1960; see p. 20, for example.

[19] C. D. Foster and M. E. Beesley, Estimating the Social Benefit of Constructing an Underground Railway in London, The Journal of the Royal Statistical Society, Vol. 126, Part 1, 1963, p. 48. (In our view, this "eye for an eye" argument is probably the weakest position one can take in defending the inclusion of consumer surplus. While permitting one mode of transport to follow one criterion and following a more rigid rule for another mode would certainly prejudice the latter with respect to the extent to which it "flourished" and was "expanded," overconsumption in both modes and poor investment policy with regard to both modes would appear to be less advisable than in just one mode.)

Again, the principal reason for excluding consumer surplus can best be summarized by a quotation of Edward Renshaw made in reference to navigation project benefit measurement:[20]

> If the full amount of the estimated (consumer) surplus were used to justify public expenditures in a one-to-one benefit-cost ratio (fulfilling the legal requirement imposed by law that benefits equal or exceed costs), there would exist no real social surplus associated with navigation investment. Use of the entire surplus to justify public investment in navigation might, therefore, be denying real surpluses associated with the same funds invested in industries which are unable to collect surpluses.

Therefore, if we exclude consumer surplus, the total measurable and allowable perceived user travel benefit is equal to the product of tripmaking and perceived travel price; referring to Figure 1. 1, if the perceived travel price is p_B, the volume of trips will be V_B and the total allowable user travel benefit will be $(p_B)(V_B)$ or equal to the area BOFC. With a perceived travel price of p_A, the total allowable perceived user benefit will be equal to the area AOGD.

This definition of perceived user benefit corresponds to the perceived user travel benefit item shown in part B of Table 1. 1, and it is suggested that this benefit item consists of both money and non-money portions to the extent that they are perceived by the traveler in his short-run tripmaking calculus.

Importantly, by defining the allowable perceived travel benefit so conservatively, we are not denying the existence of some real user travel benefit over and above that level which the traveler at the margin does experience. Rather, we are simply taking the position that the net social benefit (i. e., consumer surplus) is no more appropriate in the justification of highway investment than in the justification of automobile plant investment, for example.

It is reasonably evident that travelers are willing to pay and do pay considerably more for the privilege of traveling than the amounts indicated by the short-run demand curve; that is, in the short run the traveler is willing to pay for (or endure) the loss of travel time, and to pay for discomfort and inconvenience and for certain out-of-pocket money expenses in order to make certain trips. The short-run willingness to pay serves to indicate his perceived user travel benefit. In the long run however, he is willing to pay for vehicle ownership, operation, maintenance and repair (including interest), for vehicle accident insurance premiums and for vehicle garaging, and so forth, all of these to the extent that they are not already included in the short-run perceived travel price. This latter group of user benefits are classified in part B of Table 1. 1 as non-perceived user travel benefits. As before, we would note that the user does receive benefit or value at least to the extent of the price he does pay (for vehicle purchase plus interest, for accident insurance, etc.) and that any value he receives over and above the price he actually does pay we would recommend excluding from the allowable non-perceived user travel benefit.[21]

In adding the non-perceived items to the perceived user benefit items, some care must be exercised to include only the remainder of the user money or non-money expenses which are not already counted. As a rough guess, it seems reasonable to expect that virtually all of the vehicle ownership payments (including interest if car bought for cash or service charges if car is purchased on installment plan) and probably most of the major equipment replacement payments (such as for tires) and maintenance-repair expenses should be added to the perceived user benefits measured by the demand schedule. However, operating expenses (such as gas and oil payments)

---

[20] Edward F. Renshaw, The Measurement of the Benefits from Public Investment in Navigation Projects, Idyia Press, Chicago.

[21] Most of these non-perceived benefits can be measured directly by examining the money payments actually made by travelers.

plus toll and user tax payments probably are considered by the user in his tripmaking calculus, and thus already are included in the user benefits measured by the demand curve.

Whether specific items are included as perceived or non-perceived user benefits is not important; what is important is that all items be included in one category or the other, but not both.

Clarification should be made of two points currently plaguing engineers who attempt to conduct meaningful economy studies. The first regards the inclusion and measurement of benefits for new tripmakers using the facility or system in question (that is, benefits for the induced or additional travelers attracted after a system improvement or price change; the additional travelers would be volume V_A minus V_B in Figure 1.1), and the second regards the second-order benefits for those users remaining on other facilities from which users were diverted to the improved facility or system.

With the first group, the new induced traffic, the net benefit (i.e., trip value minus trip cost) of the tripmaking to the extra (V_A - V_B) users would be the consumer surplus shown in Figure 1.1, or area CED; it would not be the price before the price change minus the price after the change times the induced volume, or (p_B - p_A) (V_A - V_B). Since each of the induced tripmakers would begin tripmaking only according to his position on the demand schedule, his personal profit or surplus would be his value (as represented by position on the demand curve) minus the price after the change. Of course, according to our definitions, the total allowable perceived user benefit for the induced volume would be equal to p_A times (V_A - V_B) and would not include their consumer surplus.

As for travelers who remain on one facility after improvement to a second facility, an improvement which diverts some of the first facility's users to the second, it should be clear that a net benefit has resulted. These second-order effects should not be ignored (unless they can be considered external to the analysis by virtue of being outside the interest of those whose funds are being risked—usually not the case for public projects, of course), and often are not negligible. In fact, the very substantial effects noted on arterials following the construction of expressways in Los Angeles, for example, suggest that much more attention should be given to this aspect.[22]

Obviously, these latter second-order effects cannot be measured without a thorough system analysis. However, it should be emphasized that these second-order net benefits should not necessarily be included as part of the economic analysis to justify improvements. Again, these second-order effects are manifested solely as increases in consumer surplus and thus can be included or not, depending on one's judgment. Regardless of their exclusion or inclusion in the economic analysis, they should be considered and measured—at least to aid in selecting among alternative projects that might otherwise be equivalent.

1.3 DETERMINATION AND MEASUREMENT OF PERCEIVED USER PRICE AND BENEFIT

In the previous section a distinction was made between perceived and non-perceived user tripmaking benefits, wherein perceived user travel benefits were derived from the demand schedule for a given price of travel. However, determination of actual tripmaking, of the perceived user benefit and of the actual costs incurred to provide transportation service depends on a joint consideration of supply and demand conditions. On the one hand, it is necessary to know how the unit price of travel will change as more and more tripmaking is made and as the system design and operation is changed, and on the other hand, it is necessary to know what price different volumes of tripmakers will be willing to pay for the trip in question. The interplay between these two relationships will permit determination of the actual use which a facility will experience and of the benefit or value accruing to its users.

---

[22]See: J. Meyer, J. Kain, and M. Wohl, The Urban Transportation Problem, Harvard Univ. Press, Cambridge, 1965, p. 74 ff.

Because of the interdependence of supply and demand relationships, it is necessary that the supply or price-volume curve and demand curve have dependent and independent variables which are stated on a commensurate scale; for example, the unit price which travelers will have to pay for using a particular facility (as shown on the supply curve) must be stated in the same overall units as the price which travelers will be willing to pay (as shown on the demand curve). Of equal importance, the price scale for the demand curve—and thus for the supply curve as well—must be stated in perceived rather than real costs to the traveler, where the two differ. Again, those money payments which the traveler or user does pay over the longer run but which he does not consider in making short-run travel choices are not included in the price scale of the demand schedule.

1.3.1 Make-Up of Perceived User Price-Volume (or Supply) Relationships

To understand fully the make-up of the price-volume curve, a detailed breakdown is provided in Figure 1.2. This relationship should include only those items which are perceived by the user; these probably include only short-run incremental user payments (in time, effort and expense). In constructing these curves it was assumed that payments by users towards recovery of facility costs, construction, land acquisition, maintenance and administration costs are levied through the use of a uniform per vehicle-mile tax, regardless of the roadway cost or volume level (in contrast to tolls for a toll authority wherein the specific roadway costs might be recovered from, and thus the toll adjusted to, the actual volume making use of the facility).

For a specific system (or facility) whose capacity can be considered as fixed, as the volume of trips increases the major effect on the price to users will be to increase the portion for congestion, travel time and discomfort (the latter simply reflects less freedom of movements, the necessity to pay more attention to driving, increased tension, etc.). Increases in time and discomfort cost may or may not be proportional to

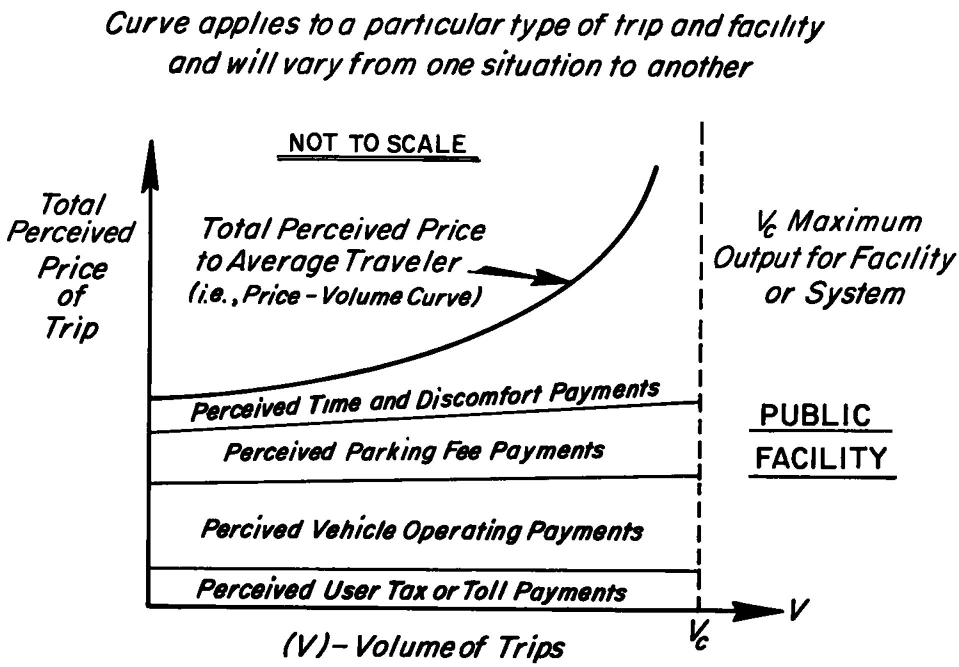

Figure 1.2. Perceived user price-volume curve for public facilities.

increases in travel time, though it can be argued that the user time and discomfort cost per minute increases faster than the travel time per minute rises.[23]

One important distinction between the price-volume curves for public facilities and those for private facilities should be made at this point.[24] Since with public facilities, the user charge to recover the facility construction and operating costs is almost uniform regardless of whether the facility cost was high or low and regardless of whether it is heavily or lightly traveled, the price-volume curve for a particular facility will continuously rise with increases in volume. Further, with public facilities the user charge to recover facility costs will not be increased if the system is expanded (even if the marginal facility costs exceed the marginal user revenues); thus, system improvements will always lower the price-volume curve, as indicated later in Figure 1.4. However, with private or toll facilities which adjust the toll charge (levied to recover the facility construction and operating costs) according to the volume using the facility and to the costs of that particular facility, the toll charge for any particular facility will usually decrease with increasing volume of usage,[25] though the remainder of the perceived user payments will be increasing (just as with the public facility case). Generally, the cost breakdowns for private facilities can be illustrated much as in Figure 1.3 (a); if the proportions of these cost items are in perspective, at fairly high volume levels little difference would exist between the unit price to users of private and public facilities.[26] Obviously, though, such a conclusion would rest heavily on the facility cost, on the cost of collecting tolls, and on the capacity of the facility, etc.

Importantly, and in contrast to the situation for public facilities, with improvements to private projects the price-volume curve would not necessarily fall below the previous one or result in price reductions to users, even with the travel time and service considerations properly accounted for in the perceived user price. Just one situation is depicted in Figure 1.3 (b); the original system A has been improved and afterwards is called system B. As a result of improvement, facility cost and service characteristics tend to offset each other, but such that the unit overall user price after improvement would be higher if the volume was below V_1 but lower if the volume was higher than V_1. This would appear to be the more usual case.[27]

1.3.2 Measurement of Perceived User Travel Benefit Allowable in Economic Analyses When Consumer Surplus Is Excluded

For the public facility case, the supply or price-volume curve shown in Figure 1.2 and the demand curve shown in Figure 1.1 individually will not permit inferences about the perceived user benefit which will result from transport systems or improvements.

---

[23] R. Zettel, op. cit., has argued the contrary, saying, "one would expect elasticity in the effective demand for time savings, that is, the value of each unit of time saved, would decrease as the number of units saved increased." Also, an interesting point arises with regard to the value of time, that is, to the cost of travel time to the user. One cannot use the actual travel time involved in tripmaking as a measure of user's perceived time expense unless that is in fact the case. If the user, for example, is a poor estimator of travel time or uses other than an absolute actual time measure to gage his time expense, then so must the engineer.

[24] The difference between private and public as intended in this discussion is that private facilities will have tolls to recover the facility construction and operating costs and that the facility costs will be spread over the volume using the facility (and thus the tolls will vary—for a given facility—according to the volume using it); public facilities will have a uniform user charge which does not vary either with the facility cost or with the volume using it, other than to an almost negligible degree.

[25] Of course, an implicit assumption has been made that the facility operating and maintenance costs (per vehicle trip) are either not increasing with increases in volume or that if they are increasing, their increases are less than the decreases due to wider distribution of the fixed costs.

[26] Again, the unit price for both private and public includes all time, expense, and effort payments perceived by users, and not just toll or other money payments.

[27] In other cases, the total user price curve after improvement could at every point lie above the before improvement curve, or it could at every point lie below the before improvement.

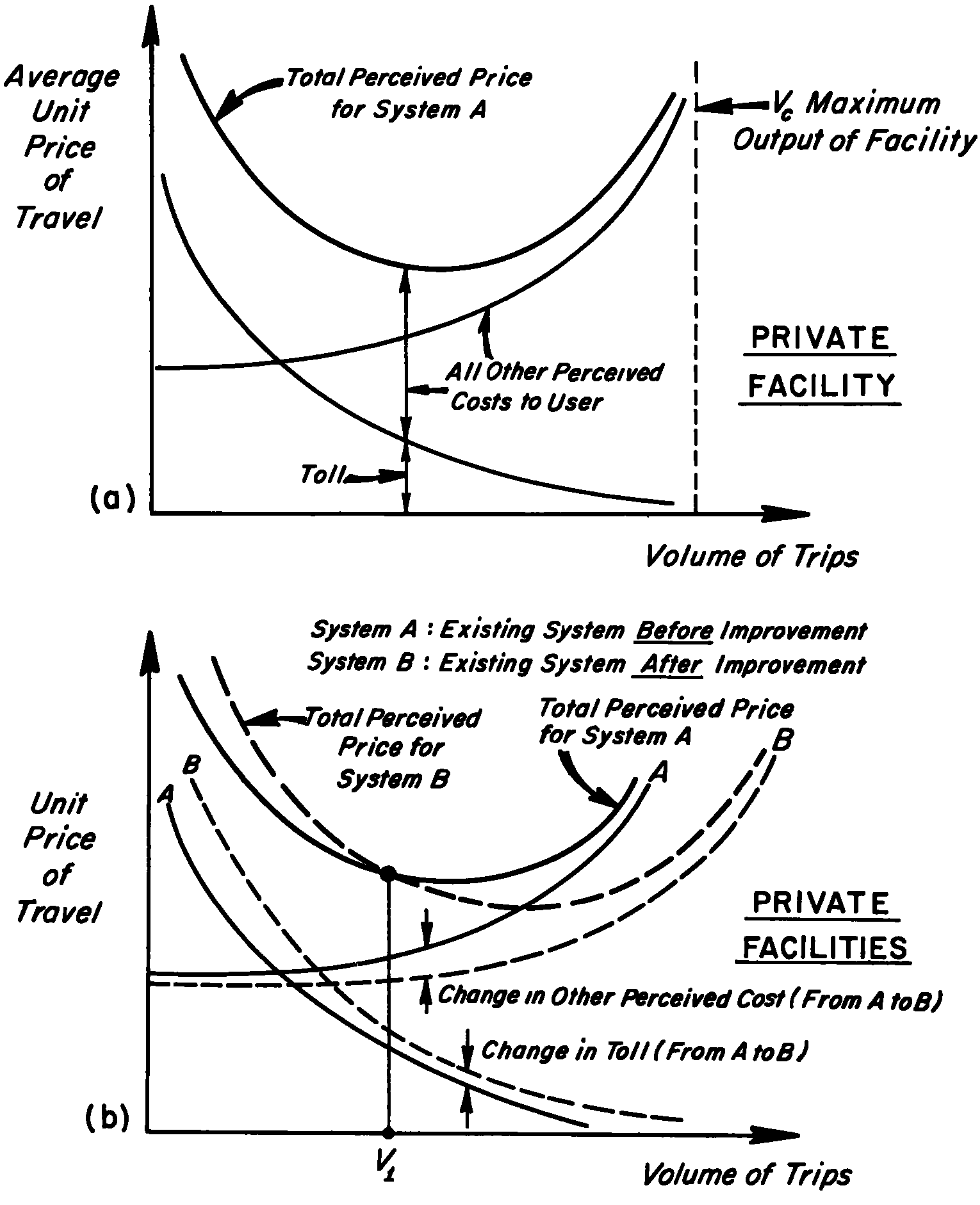

Figure 1.3. (a) Perceived user price-volume curve for private facilities, and (b) change in perceived user price-volume curve with improvement to private facility.

Taken together, however, these relationships will permit us to determine the actual volume usage or demand for travel on a system or facility, and, ultimately, the user benefit from such usage; this interplay and the resulting actual demand or volume usage together with the corresponding price of travel is shown in Figure 1.4. (Actually, this interplay probably should be determined on an hour by hour basis, etc. Only one such time period of analysis is shown in Figure 1.4.)

With System A (Fig. 1.4) the resulting price would be p_A and the volume V_A. As noted previously, the allowable perceived user travel benefit is indicated by the hori-

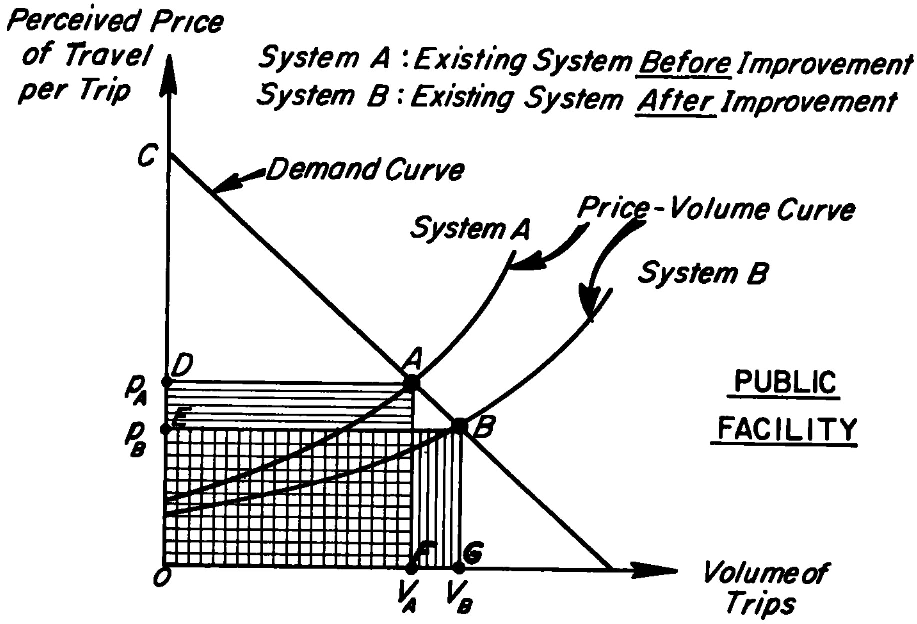

Figure 1.4. Interaction of price-volume curves and demand curve showing allowable perceived user benefits.

zontal shading, or AFOD. Similarly, with System B the allowable perceived benefit is shown by vertical shading, or BGOE.[28]

Once the equilibrium point, or intersection between price-volume and demand curves, has been determined the total system costs (or costs to those whose resources are being risked) as listed in A of Table 1.1 can be computed. The volume which will actually use the facility will have been determined, and the specific design, service, and operation details therefore will be set; the system costs can be estimated directly from these inputs. To the extent that perceived monetary or non-monetary user price items illustrated in Figure 1.2 (and thus Figure 1.4) are identical to like items in listing A of Table 1.1, they will also serve as adequate measures of these items of real system cost. However, where they are dissimilar, other measures of the appropriate real user cost items must be made and included. (For additional discussion of this point, see section 1.4.)

The price-volume curves illustrated previously represented "average" conditions. Since these curves were used together with the demand curves to estimate final or actual demand the implicit assumption was made that travel conditions and prices among those making up the actual demand were uniform; in other words, if the volumes are scaled in vehicles per hour, then it has been assumed that each vehicle in that hour of traffic flow is afforded approximately the same trip time, etc., and that each vehicle and its occupants are homogeneous with respect to the value of time, etc., and thus with respect to price.

1.3.3 Summary of Perceived User Travel Benefit Specifications for Varying Project Conditions

The earlier discussion has dealt primarily with perceived user travel benefit, with the extent to which this user benefit might or might not be included in the economic

[28] Again, benefit only to the extent that the user does pay for is included; thus, consumer surplus is excluded.

analysis, and has noted how such user benefits can or may change with improvements to an existing system or with development of different system capacity levels.

To capsulize this information for the public facility case, Table 1.2 should be helpful; furthermore, it is constructed so that it is equally applicable to an improvement in an existing system, to the construction of an entirely new system, or to comparison of the consequences of different system improvements (or levels of improvement).

TABLE 1.2

VARIOUS MEASURES OF PERCEIVED USER TRAVEL BENEFIT*
(See Figure 1.4)

Item	I. Value of Item Indicated with System A	System B
1. Travel volume	V_A	V_B
2. Perceived user price	p_A	p_B
3. Total allowable perceived user benefit (excluding consumer surplus)	$(p_A)(V_A)$	$(p_B)(V_B)$
4. Total perceived user value or benefit (including consumer surplus)**	$(p_A)(V_A) + \Delta\overline{ACD}$	$(p_B)(V_B) + \Delta\overline{BCE}$
5. Total perceived user net benefit (i.e., total value minus price) or consumer surplus	$\Delta\overline{ACD}$	$\Delta\overline{BCE}$
	II. Change in Value When Comparing System B with System A	
6. Change in tripmaking volume	$(V_B - V_A)$	
7. Change in perceived user "price"	$(p_B - p_A)$	
8. Change in total allowable perceived user benefit (excluding consumer surplus)	$(p_B)(V_B) - (p_A)(V_A)$	
9. Change in total perceived user benefit (including consumer surplus)	$\frac{1}{2}(V_B - V_A)(p_B + p_A)$	
10. Change in total perceived user net benefit (i.e., change in consumer surplus)†	$\frac{1}{2}(p_A - p_B)(V_A + V_B)$	

*It is important to note that only items No's. 3 and 8 are allowable for an economic analysis, according to our framework. The others are indeed measures of benefit, but excludable, nonetheless, for our definitions. Also, a one-price or uniform user charge is assumed.

**The symbol Δ stands for triangle.

†Most highway engineering economy studies define highway benefit as being equal to this expression. In contrast to the other measures of benefit in this table, the user travel costs have been deducted. Thus, this measure corresponds to change in user profit rather than benefit.

To be more specific, according to our definitions the allowable perceived user travel benefit (i. e., without consumer surplus) for the cases would be as follows:

Case 1: Construction of Entirely New System (call it "A"). Compute values as shown in item No. 3, of Table 1.2, for System A.

Case 2: Incremental Improvement of an Existing System A to Level of System B. Compute incremental values as shown in item No. 8, of Table 1.2.

Case 3: Construction of New Proposed System A and Incremental Improvement of Proposed System A to Level of System B. Compute the incremental values as shown in No. 8, part II of Table 1.2; also, compute values of System A as shown in item No. 3.

It is clear that our definition of the allowable portion of perceived user benefit is distinctly different from that often used by others. As noted earlier, user benefit as defined by highway engineers often has a connotation of "user cost reduction," rather than that of user value as practiced herein; thus whereas others may define all user cost reduction as user benefit, we will not do so.[29] More importantly, according to our procedure all net user benefit (i. e., consumer surplus) that he does not pay for is excluded from the benefit calculations.

In essence, most traditional highway engineering economy studies justify highway improvements almost exclusively on the basis of increases in consumer surplus accruing to the users. Our procedure, by contrast, adopts a more conservative posture that closely parallels the economic justification analyses common to private industry.

Definitionally, our procedure contrasts with that followed by others, such as Mohring, Kuhn, and Zettel,[30] but appears to be consistent with the treatment of Maass, Hirshleifer, and of Beckmann, and that of most economists.[31] We feel, though, that our definitions and structure as presented herein will be more useful in the long run.

However, should one prefer to include consumer surplus in the benefit totals to be used for economic analysis, the appropriate measures to be used in the analysis would be as follows:

Case 1: Construction of Entirely New System (call it "A"). Compute values as shown in item No. 4, of Table 1.2, for System A.

Case 2: Incremental Improvement of An Existing System A to Level of System B. Compute incremental values as shown in item No. 9, of Table 1.2.

---

[29] One may envision circumstances where our procedure would appear nonsensical and inconsistent; usually, though, these circumstances arise only because one fails to consider both the cost and benefit aspects. For example, imagine that the demand schedule is vertical, and that a system improvement lowers the supply or user price curve; in this case, and for our definitions, clearly the user benefit will be reduced after improvement—even though one "knows" that the user is certainly "better off." While the allowable user benefit has been reduced, by our definitions, it must be emphasized that the user cost (both unit and in total) has also been reduced. Also, while it is evident that in this situation users would be better off, the question is whether or not this net social benefit should be included in the allowable benefit totals used to justify improvements.

[30] Op. cit.

[31] M. Beckmann, C. B. McGuire, and C. B. Winsten, Studies in the Economics of Transportation, Yale University Press, 1956, Chap. 2; Arthur Maass, et al, Design of Water-Resource Systems, Harvard University Press, Cambridge, 1962; J. Hirshleifer, et al, Water Supply, University of Chicago Press, 1960.

Case 3: Construction of New Proposed System A and Incremental Improvement of Proposed System A to Level of System B. Compute the incremental values as shown in item No. 9 of Table 1.2; also, compute values of System A as shown in item No. 4.

1.3.4 Procedures for Measurement of Perceived User Travel Benefit and Net Perceived Benefit for Diverted, Induced, and Growth Traffic, and Their Critique

Earlier, the demand function was characterized as dependent on a number of important system and environmental variables and factors; also, it was noted that the demand curve will tend to shift upwards and to the right with general growth in population and income, somewhat as shown in Figure 1.5. These demand curve shifts result in the so-called "diverted, induced, and growth" traffic which will use the new or improved facility. Figure 1.5 illustrates the user price-volume curve before and after system improvement and includes demand curves for five successive years.

Using Figure 1.5, one can determine how much traffic will use the road during each year if the system remains unchanged (System A) or if the system is improved (System B).[32] The curves indicate that in earlier years the annual volume increases will be larger than those for succeeding years since each year the prospective traffic congestion will be higher than that for the preceding year (i.e., the unit price will increase each year), and so forth. For System A, without improvement, the increase in traffic volume from $V_{A,0}$ to $V_{A,1}$ and from $V_{A,1}$ to $V_{A,2}$ is (so-called) "normal traffic growth" for the first and second years. For System B, the improved system, the traffic growth from $V_{B,0}$ to $V_{B,1}$ and from $V_{B,1}$ to $V_{B,2}$, and so forth, can also be regarded as normal traffic growth. Further, where System B represents a replacement of or improvement of System A, the base traffic which would have continued to use System A if it had not been improved (or, $V_{A,0}$) but instead is using System B during its first full year is the "diverted traffic"; therefore, the remaining traffic on the improved System B during the first full year of its operation, or $V_{B,1}$ minus $V_{A,0}$, includes the "induced" and normal traffic growth portions. The induced traffic portion is equal to $V_{B,0}$ minus $V_{A,0}$ and the normal traffic growth portion is equal to $V_{B,1}$ minus $V_{B,0}$.

Our definition of allowable user benefit excludes consumer surplus and the price to the traveler is assumed to be his perceived price (since the demand curve is used for traffic prediction purposes). Thus, there is no necessity to distinguish between user benefit for diverted trips and that for induced trips; it is only necessary to know the unit price of travel and the total amount of traffic which uses or would have used the system at that price.

In other words, for the method as outlined, the total allowable perceived user benefit for System B during the first full year (year 1) of operation is $V_{B,1}$ times $p_{B,1}$ (and then placed on an annual basis), and that for the second year would be $V_{B,2}$ times $p_{B,2}$, etc. For System A without improvement, the total allowable perceived user benefit would be $V_{A,0}$ times $p_{A,0}$ during year "0", and would be $V_{A,1}$ times $p_{A,1}$ during year "1", etc.[33]

[32] It is assumed in this example that System A was in existence during year 0 (i.e., the present year), while the improvement will not be in existence until the end of year 0.

[33] The benefit streams for A and B will differ slightly since System A will accrue user benefit in year 0 since it was already in existence, whereas it will take some time (say a year) as well as a commitment of capital to improve the facility before user benefits can begin on System B; a one year lag has been assumed here, with improvement (or construction) taking place during year 0.

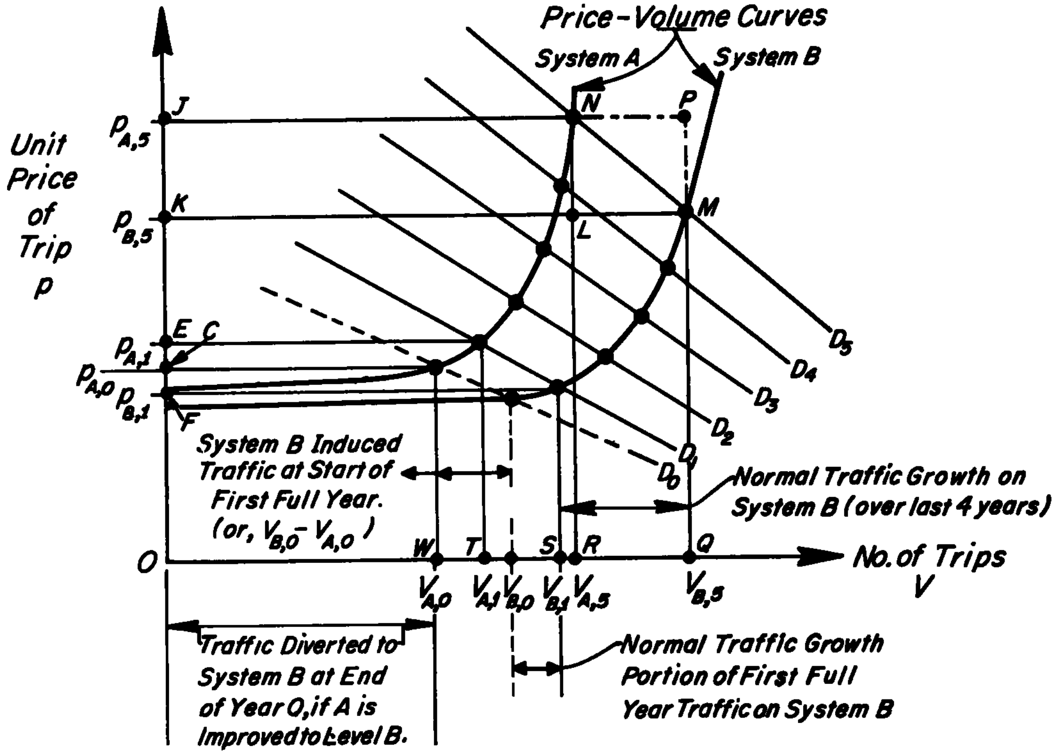

Figure 1.5. Supply and demand curves for system with or without improvement.

Notationally, the total allowable perceived user benefit to be measured in the x th year for System y would be simply

$$\text{Total allowable perceived user benefit} = (V_{y,x})\,(p_{y,x}) \qquad 1.1$$

in x th year for System y.

Also, if one desires to compare the benefits and costs of various alternatives, it is important that the time scale be handled properly. In other words, it makes little sense to compare directly the benefits and costs of System A in the year 0 with those of System B in year 1, etc.

These aspects of benefit measurement and economic analysis have been handled in different ways in various texts. Oglesby and Hewes point out that "if an analysis indicates that traffic on a proposed project will increase with time, this increase should be recognized in the economy study."[34] However, in their detailed example, in which the benefits and costs of an improved facility are compared with those of the existing roadway, they note: "The present average annual daily traffic as determined by counts is 800 passenger cars, 100 pickups, 60 single-unit trucks, and 30 combination vehicles. This volume is assumed to remain constant for the study period.[35] Obviously, this constant annual traffic assumption is hardly typical; relative to the more common example illustrated in Figure 1.5, it appears that Oglesby and Hewes have assumed that only one demand curve exists over time and that demand can simply be represented by

[34]C. H. Oglesby and L. I. Hewes, Highway Engineering, John Wiley and Sons, Inc., New York, 1963 (2nd Ed.), p. 84–85.

[35]Ibid., p. 90.

the D_0 demand curve. Also, they have assumed that existing and improved roadways will have the same volume of travel. In essence, they have assumed that the demand curve is vertical (or, in the jargon of the economist, that demand is perfectly inelastic with respect to the price of travel) and thus that no matter how much you improve the road no more people will use it or no more frequent use will be made of it.

The Oglesby and Hewes example differs from our procedure in another important respect. Oglesby and Hewes include two categories of cost in their economic analyses: (a) road user costs (but not including vehicle time depreciation costs, or those for parking, etc.); and (b) highway costs (both capital and continuing costs). However, in their example, benefit is defined as the difference between road user costs for the alternative of lower first cost and those for the alternative of higher first cost. Thus, their definition of benefit is different from that outlined in earlier sections and is equivalent to defining benefit as equal to the change in consumer surplus accruing to users.

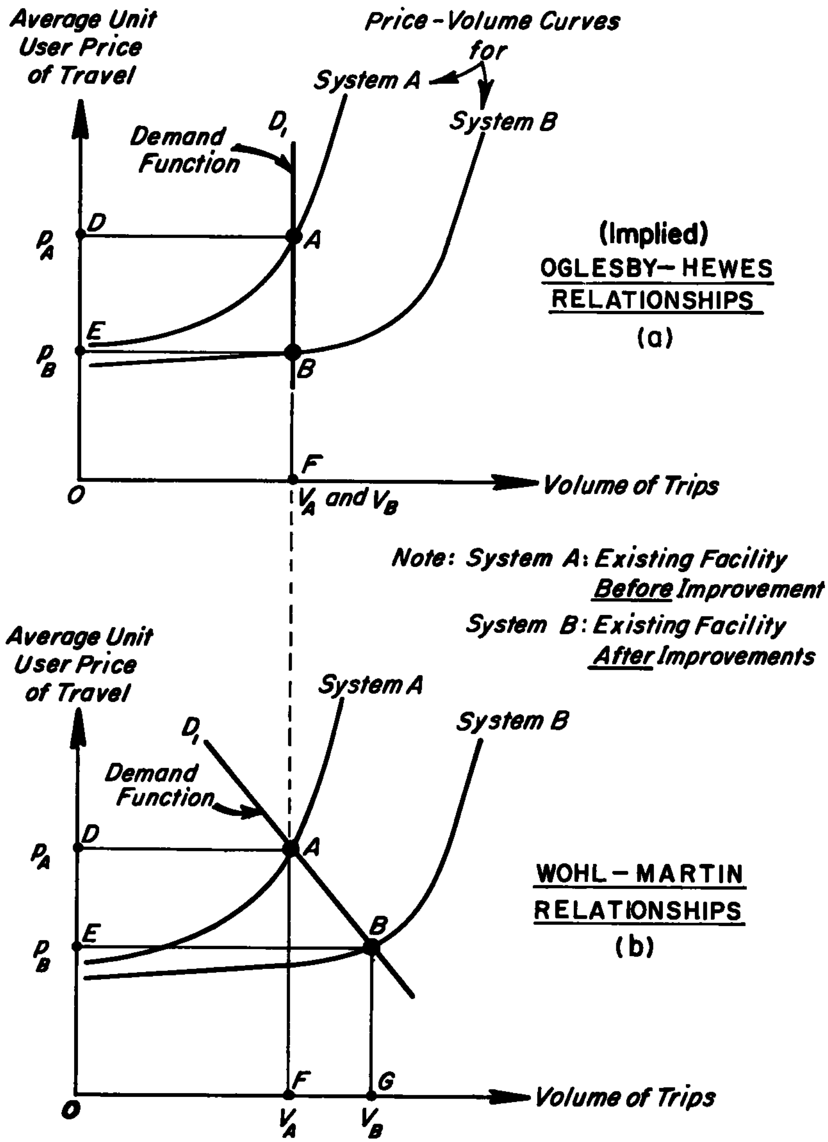

Figure 1.6. Perceived user cost and benefit relationships for different procedures.

The implications of these differences can best be shown by referring to the relationships in Figure 1.6. As noted earlier, the Oglesby and Hewes example assumes that the improved facility or System B in Figure 1.6(a) will attract no more traffic volume than System A (the existing facility before improvement); however, it would appear that such an assumption is unrealistic and that a demand curve with somewhat less than an infinitely large slope would be more appropriate. Thus, the demand curve and relationships in Figure 1.6(b) appear to have more validity. Using the supply (user price-volume) and demand relationships of Figure 1.6(b) and using Oglesby and Hewes definition of benefit (i.e., road user costs for System A minus road user costs for System B), the benefits from improvement of System A to the level of System B would be

$$\text{Improvement benefits} = (p_A)(V_A) - (p_B)(V_B)$$

$$= (\text{area } \overline{ADOF}) - (\text{area } \overline{BEOG}) \qquad (1.2.a)$$

It should be clear that the benefits when defined and computed as Oglesby and Hewes suggest will not necessarily be positive, but at times can be negative, depending on the shape of the demand curve (i.e., depending on the demand elasticities) and on the reduction of the user price-volume relationship. Thus in those instances where traffic volume increases are taken into account we would assume that Oglesby would calculate highway benefits as follows (see Fig. 1.6.b):

$$\text{Improvement benefits} = \tfrac{1}{2}(p_A - p_B)(V_A + V_B)$$

$$= \text{area } \overline{ABED} \qquad (1.2.b)$$

Again, this formulation of highway improvement benefit is equivalent to computing the change in consumer surplus accruing to highway users. (See Item No. 10 in Table 1.2.)

The AASHO ("Red Book") procedure realistically accounts for increases in traffic flow which usually result from roadway improvements,[36] but appears to handle the computation of user benefits improperly.

In describing the traffic flow data which should be considered in economic analyses, and in detailing how to use the data, the AASHO method notes that:[37]

> . . . Road user costs include all traffic directly involved or affected by the improvement. One alternative may include road user costs for vehicles operating on a new or improved route and also those continuing to operate on one or more parallel or connecting routes on which the traffic flow is affected by the improvement.
>
> * * *
>
> Three steps are necessary to determine the value of. . . [the annual average daily traffic volume over the analysis time period] for each section of highway in an analysis:
>
> 1. Estimate the annual average daily traffic that will use the section upon its completion;
> 2. Determine the number of years for which the analysis is to be made, and the expansion factor for traffic on the section during this period; and
> 3. Calculate an expanded annual average daily traffic volume that is a representative or average value for the period of analysis.

---

[36] It is difficult to imagine situations where this did not happen for public facilities since the price is always decreased because of the peculiarities of the pricing mechanism.

[37] Road User Benefit Analyses for Highway Improvements, American Association of State Highway Officials, 1960, Washington, D.C., p. 14 and 15.

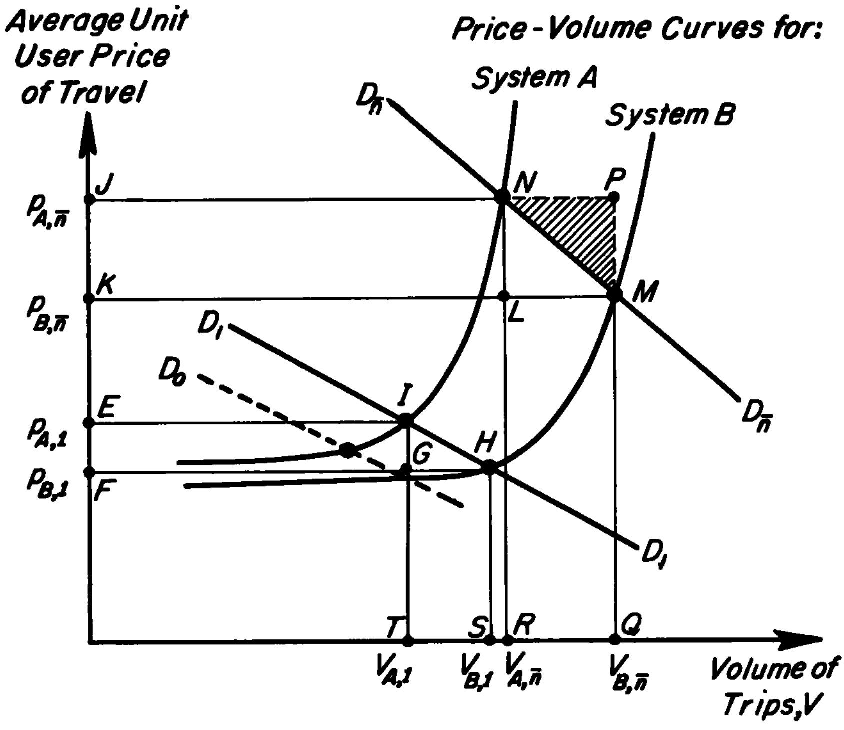

Figure 1.7. Perceived user cost and benefit relationships for AASHO procedure.

The annual average daily traffic volume that is estimated to use the facility upon its completion (part 1 above) will include the total diverted and induced traffic using the new facility during the first full year; referring to Figure 1.7, this first full year volume is determined from the intersection of D_1 and the supply curve for System B and is equal to $V_{B, 1}$. (Ignore for the time being the conversion of the hourly traffic flow V to an annual daily traffic volume figure.) Then, following steps 2 and 3 above, let us assume that $D_{\bar{n}}$ is the demand curve which is representative of the demand conditions over the period of analysis, and thus represents the average volume-demand conditions over the n-year period of analysis; with such an assumption, the flow $V_{B, \bar{n}}$ will represent the System B average annual daily traffic volume to be used for the AASHO benefit-cost analysis.

The volume $V_{B, \bar{n}}$ is used in all the examples of the AASHO procedure to determine the user cost savings and thus user benefits but, most importantly, is applied to the unit user cost data for both existing (before improvement) and proposed (after improvement) alternatives.[38] In other words, the AASHO procedure multiplies the unit user cost for the existing facility (before improvement) times the future representative volume, $V_{B, \bar{n}}$, and then subtracts the product of the unit user cost for the proposed facility (after improvement) times the representative volume $V_{B, \bar{n}}$; this is equivalent of course to multiplying the representative future volume $V_{B, \bar{n}}$ times the difference between the user cost of the existing and the proposed facility.

Referring to Figure 1.7 and reviewing the analysis according to the intended AASHO definitions, which presumably was to include as user benefit all net value gained by the user (that is, to include all positive gains that he accrues from the improvement, including consumer surplus), it is clear that AASHO should have measured area JKMN,

[38] Ibid., p. 30, for example.

or all consumer surplus added as a result of the improvement.[39] However, if we follow the AASHO procedure and determine the net benefit by multiplying the representative volume on the improved facility times the difference between the unit user cost of the existing facility (before improvement) and that of the proposed facility (after improvement), the following would be obtained:

Net user benefit (or user cost reduction from improvement) =

$$\text{area } \overline{JKMP} = (V_{B,\bar{n}})(p_{A,\bar{n}} - p_{B,\bar{n}}) \quad (1.3)$$

In other words, the AASHO procedure would incorrectly include more user benefit than is justified even under a full area consumer surplus criterion. Briefly, only those users who would have used the existing facility (System A) during the $\bar{n}$th year and in turn who will be diverted to the proposed facility (System B), or volume $V_{A,\bar{n}}$, will gain the full cost reduction from $p_{A,\bar{n}}$ to $p_{B,\bar{n}}$; the other users (or $V_{B,\bar{n}}$ minus $V_{A,\bar{n}}$) will accrue surplus only to the extent of the difference between their position on the demand curve (the price at which they would start traveling) and the price $p_{B,\bar{n}}$. In brief, the shaded area $\overline{NPM}$ is improperly included by the AASHO procedure.

Another important point to be noted and taken account of is that regarding the conditions under which the specific unit user costs are estimated. The AASHO Red Book is not too specific or clear on the matter, but does refer to the combined user costs "... for the type of highway and operating conditions thereon."[40] From their examples it can be assumed that they intended using them as we have noted in the above formulation and in Figure 1.7. In short, the relevant user costs to be used are not the present-day user costs, but the unit user costs which would occur during the n-year period of analysis and which, on the average, would result from the $\bar{n}$th year volume. Many studies quite improperly use the present-day unit user costs in computing the user benefits over the life of the facility; that is, they use the difference between $p_{A,0}$ and $p_{B,0}$ or perhaps that between $p_{A,1}$ and $p_{B,1}$ for computing the unit user benefit rather than the difference between $p_{A,\bar{n}}$ and $p_{B,\bar{n}}$.[41]

Summarizing, the AASHO procedure is concerned with the measurement of the user cost reductions or so-called user benefit during a representative $\bar{n}$th year after opening of the proposed facility; for those road user benefit analyses in which it is desired to include consumer surplus (i.e., the full area concept), the resultant user benefit for the n th year should be

(AASHO) Net user benefit (including consumer surplus) =

$$(V_{B,\bar{n}})(p_{A,\bar{n}} - p_{B,\bar{n}}) - \tfrac{1}{2}(V_{B,\bar{n}} - V_{A,\bar{n}})(p_{A,\bar{n}} - p_{B,\bar{n}}) = \quad (1.4)$$

$$\tfrac{1}{2}(V_{A,\bar{n}} + V_{B,\bar{n}})(p_{A,\bar{n}} - p_{B,\bar{n}}) \quad (1.5)$$

However, the road user benefit for the AASHO procedure for the $\bar{n}$th year in the case where consumer surplus for the new tripmaking is not included would be

(AASHO) Net user benefit (w/o consumer surplus for new trips) =

$$(V_{A,\bar{n}})(p_{A,\bar{n}} - p_{B,\bar{n}}) \quad (1.6)$$

---

[39] Here to correspond with the AASHO analysis, $D_{\bar{n}}$ is assumed to be representative of or an average for conditions over n years.

[40] AASHO, op. cit., p. 15.

[41] As noted earlier, the analysis and computation of user benefits, as defined either by our method or by AASHO, should be made year by year and accumulated (after proper discounting of future benefits) over the life of the facility, rather than being placed on a representative year basis. However, this short-cut approximation will be regarded as adequate for the time being.

For the procedure which we prefer to follow, wherein benefit is defined as trip-making value to the extent that travelers actually pay for it and thus does not include consumer surplus, the total perceived and allowable user benefit in the x th year would be

$$\text{User benefit of System A in x th year} = (V_{A,x})\,(p_{A,x}) \tag{1.7}$$

$$\text{User benefit of System B in x th year} = (V_{B,x})\,(p_{B,x}) \tag{1.8}$$

The change in benefits resulting from improvement can be computed directly as the difference between these two Eqs. 1.7 and 1.8. Furthermore, and in contrast to most other procedures, it is suggested that the user benefits for each system or alternative being analyzed be computed separately for each year over the period of analysis rather than being placed on some "average" or representative year basis. The reason for suggesting this will become more apparent as the arithmetic for capital budgeting and decision-making is discussed in the next chapter. Also, it should be repeated that changes in user costs and benefits resulting from system improvement usually are generally reflected in both the cost and benefit sides of the accounting ledger.

1.4 SUMMARY AND CONCLUDING REMARKS

In this chapter we have attempted to provide a framework for defining benefits and costs in a manner which is consistent with the body of knowledge and the principles common to the economist. While the adoption of these definitions requires a considerable departure from those usually presented in the highway engineering literature, such a change will permit analysis of more general engineering design situations and will avoid the difficulties which arise from having one "language" for engineers and another for economists, the latter being those upon whom engineers must rely for the economic theory to be used in engineering design.

Another principal difference between the recommendations outlined in this chapter and those often followed in highway economy studies is that we have advised against the inclusion of consumer surplus in the benefit totals allowable for the economic justification of public investments. However, in making this conservative recommendation, we not only detail the primary reasons for so doing (see section 1.2.3) but also emphasize that the matter of including or excluding consumer surplus is at least partially a judgmental issue and thus cannot be argued strictly on economic grounds.

Finally, we would note that following a procedure such as we have suggested will fully permit the engineer to answer both important engineering design questions—Why do it at all? and Why do it this way?—while the more traditional procedures often permit analysis of only the latter question.

CHAPTER TWO

The Evaluation of Alternative Engineering Designs: Methods of Analysis

2.1 INTRODUCTION

Once the system costs and benefits, however defined, have been determined for the alternative designs or systems, economic comparisons can be made to ascertain the most attractive capital investment alternative; it is important to note that the costs and benefits must be placed on a proper time scale (that is, according to the year of their occurrence) and that the alternatives include among them the null or "do nothing" possibility.

The most common capital rationing or capital budgeting techniques,[42] and the ones with which we deal, are (a) annual cost method, (b) benefit-cost ratio method, (c) rate-of-return method, and (d) net present value (or, net present worth) method.

2.2 INTEREST OR THE TIME VALUE OF MONEY, CAPITAL RECOVERY, AND RELATED PROBLEMS

Economic evaluations should recognize the importance of the time scale, and the ability of money to earn income over time, i.e., the "time value of money." Quite simply, a $1000.00 gift today is worth considerably more than a $1000.00 gift five years from today, since the former can be invested in the interim and thus 5 years from now the $1000 will be enhanced by the total earnings over the 5-year period. Or, to put the matter another way, should you lend a $100.00 to an associate for five years, at the end of that period you probably would require repayment of not only the $100.00 principal but also the accumulated interest (foregone), since you forfeited the opportunity to earn interest or income during the 5-year period.[43] Furthermore, as a lender you could have asked that your borrower repay the note or loan in one of a number of ways, all of which are in every way equivalent, if, of course, the interest or discount rate is constant over the period of the loan and if your other investment opportunities have an equal return and risk. For example, you could have asked for a single payment at the end of the 5 years, or for equal payments at the end of each year, or for annual payment of interest on the principal amount of the loan plus the principal at the end of the 5-year period.

The three methods of payment and the formulas used in computing the payments are shown in Table 2.1; the example assumes a present-day cash loan of $100 (net), full

---

[42] A number of excellent references on this subject are available, to include: E. L. Grant and W. G. Ireson, Principles of Engineering Economy, The Ronald Press Co., New York, 1960; Joel Dean, Capital Budgeting, Columbia University Press, New York, 1951; Ezra Solomon, "The Arithmetic of Capital-Budgeting Decisions," and James H. Lorie and L. J. Savage, "Three Problems in Rationing Capital," both articles in The Management of Corporate Capital, edited by Ezra Solomon, The Free Press of Glencoe, New York, 1964; H. Bierman and S. Smidt, The Capital Budgeting Decision, The Macmillan Company, New York, 1966; Jack Hirshleifer, J. DeHaven and J. Milliman, Water Supply Economics, Technology, and Policy, University of Chicago Press, Chicago, 1960.

[43] Notice the equivalence that was implied between interest or income foregone and so-called opportunity cost (that is, the cost of a lost opportunity).

TABLE 2.1

REPAYMENT SCHEDULES FOR 5-YEAR LOAN OF $100 AT 6 PERCENT INTEREST*

(t) No. of Full Years Passed Since Loan Made	Interest Owed at End of t th Year (prior to payment)	Principal Owed at End of t th Year (prior to payment)	Total Payment at End of t th Year	Present Worth of t th Year Payment
Method I: Single Lump Sum Payment at End of n Year Loan				
			$(S_{i,t})$	
0 (i.e., start of loan)	—	$100.00	—	—
1	$ 6.00	100.00	—	—
2	12.36	100.00	—	—
3	19.10	100.00	—	—
4	26.24	100.00	—	—
5	33.81	100.00	$133.81	$100.00
			$\sum_{t=1}^{n} S_{i,t} =$ $133.81	PV = $100.00
Method II: Equal or Uniform Payments Over n Years				
			$(A_{i,t})$	
0	—	$100.00	—	—
1	$ 6.00	100.00	$ 23.74	$ 22.40
2	4.94	82.26	23.74	21.13
3	3.81	63.46	23.74	19.93
4	2.61	43.53	23.74	18.80
5	1.34	22.40	23.74	17.74
				PV = $100.00

Method I: $PV = \sum_{t=1}^{n} (pwf'_{i,t})(S_{i,t})$

Method II: $PV = \sum_{t=1}^{n} (pwf'_{i,t})(A_{i,t})$

Method III: Annual Interest Payment Over n Years plus Principal at End of n th Year

			$(E_{i,t})$	
0	—	$100.00	—	—
1	$ 6.00	100.00	$ 6.00	$ 5.66
2	6.00	100.00	6.00	5.34
3	6.00	100.00	6.00	5.04
4	6.00	100.00	6.00	4.75
5	6.00	100.00	106.00	79.21
				PV = $100.00

$$PV = \sum_{t=1}^{n} (pwf'_{i,t})(E_{i,t})$$

*Symbols adapted mainly from E. L. Grant and W. Ireson, op. cit., Chap. 4.

NOTATION FOR TABLE 2.1

t = No. of full years (or interest periods) passed since loan was made.

i = Rate of interest (per interest period).

n = No. of years (or interest periods) of loan.

p = Principal amount of loan.

PV = Present value of money,

= $\sum_{t=1}^{n} (pwf'_{i,t})$ (annual cost or payment in t th year),

where $pwf'_{i,t}$ = present worth factor for discounting payments (or costs, etc.) made in t th year to their equivalent value in present year (i.e., year 0).

$$pwf'_{i,t} = \frac{1}{(1+i)^t}$$

Method I $S_{i,t}$ = Annual payment made at end of t th year whereby all principal and interest is paid in a single lump sum payment at end of n th year (at interest i);

when $t<n$, $S_{i,t} = 0$, and

when $t = n$, $S_{i,t} = P(1+i)^n$,

or $P(caf'_{i,n})$,

where $caf'_{i,n}$ is the single payment compound amount factor.

Method II $A_{i,t}$ = Annual uniform end-of-the year payment made at the end of t th year over n years at interest i

$= P\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$, or $(P)(crf_{i,n})$,

where $crf_{i,n}$ is the capital recovery factor.

Method III $E_{i,t}$ = Annual payment made at end of t th year over n years whereby principal is repaid at end of n th year, and interest is paid annually;

when $t<n$, $E_{i,t} = Pi$, and

when $t = n$, $E_{i,n} = P + Pi$.

repayment within 5 years, and an interest (or discount) rate of 6 percent. To demonstrate that the three methods of repayment are indeed equal over the 5-year period we have computed the present value of the repayments, that is, the sum of the repayments made over n years with each payment discounted to its present value.

Again, it should be noted that these three repayment methods are equivalent only for the assumed interest or discount rate, and only so long as the return to be gained from other investments is the same as the discount rate used in these formulas.

In simple terms, over the n-year period each of the three methods has provided the lender with an interest or income of i percent per annum on his capital loan and has recovered his capital of amount P. The only difference is when the payments of interest and capital recovery are made. It may be helpful to note that the second method (or, Method II) is that which most people commonly experience with home mortgages or with installment loans of one sort or another.

Intuitively, most of us have a feeling for the extent to which future costs or benefits are "devalued" or discounted relative to present-day values. Given the choice between receiving something desirable today or receiving it tomorrow, most of us will prefer receiving it today; or, given the choice of doing something unpleasant either today or tomorrow, most of us will prefer delaying it until tomorrow. Present worth or present value data are particularly useful in noting more precisely the extent to which future costs or benefits are devalued when compared with present-day costs or benefits; for this purpose, the present value or present worth formula ($pwf'_{i,t}$) was used to construct the illustration shown in Figure 2.1 for three interest rates—3, 6, and 8 percent

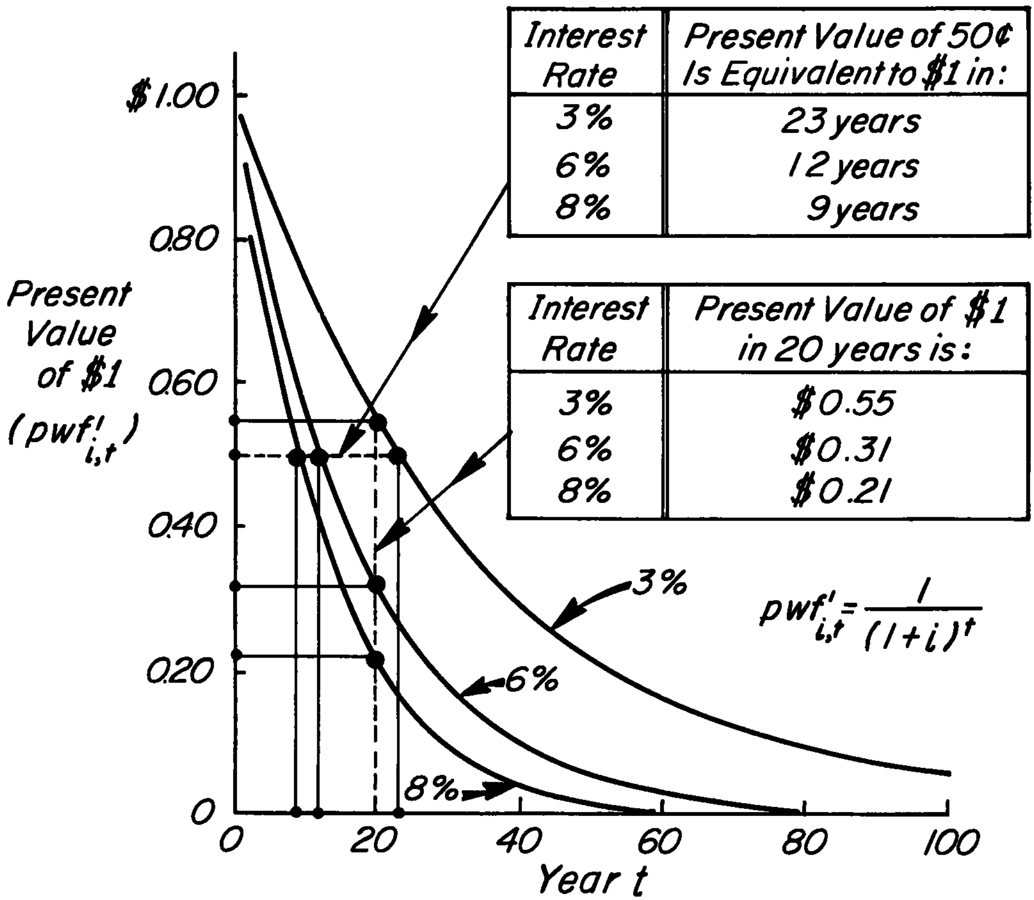

Figure 2.1. Present value of $1 spent or earned in year t for different interest rates i.

TABLE 2.2

PRESENT WORTH OR VALUE FACTOR AT YEAR t FOR 6 PERCENT INTEREST*

Year	$pwf'_{i,t}$
1	0.9434
2	0.8900
3	0.8396
4	0.7921
5	0.7473
10	0.5584
15	0.4173
20	0.3118
25	0.2330
30	0.1741
40	0.0972
50	0.0543
60	0.0303
70	0.0169
80	0.0095
90	0.0053
100	0.0029

*Grant, op. cit., Table E-13.

per annum; the numerical values for the 6 percent interest rate are given in Table 2.2. It can be shown that the present value of money spent or earned in future years (or at time t) decreases with increases in time t, that the present value of money at any time t decreases exponentially with the interest rate, that the percentage decrease in present value (for a given interest rate) remains constant with increases in time t, and that at any point in time the percentage decrease in present value occurring with an increase in the interest rate is linearly related to time t, and inversely and linearly related to the interest rate.

Several important things arise from our consideration of the time value of money. For any reasonably typical interest rate, say 6 percent, money in the far future has little value at present; in Table 2.2, for example, a $1.00 in 10 years is worth only $0.56 today and $1.00 in 20 years is worth only $0.31 today. In 40 years, $1.00 is not even equivalent to $0.10 today. Visualize this aspect in two ways: (a) a toll road operator, for example, will have little interest in the toll revenues he is to obtain 40 years hence, and by the same token a public highway department should regard lightly any benefits (tangible or not) to be anticipated far into the future; and (b) neither a toll road operator nor a state highway department should be particularly concerned about expenditures (for roadway improvement or replacement) which will be made in 40 to 50 years since these costs (just as the benefits) are not highly valued relative to those taking place in the present or near future.

Capital recovery, in simplest terms, pertains to the recovery of the capital invested in any project—over and above the interest on the capital. The purpose of recovering capital is fundamental and is to insure that the continuance of "income" or benefit (whatever its form) will be assured after the end of the project life. In other words, presumably at the end of the service life, the initial project will no longer continue to produce income on the capital unless the capital is replaced; thus if the initial capital has been entirely dissipated (and no capital has been recovered), then no further income or benefit will be forthcoming. Conversely, if the project has an indefinitely long life, obviously the replacement or recovery of capital is of little importance.

In all three of the repayment schedules in Table 2.1, capital as well as interest was recovered by repayments, though in two methods all capital was recovered at the end of the service life (or loan period for that analysis) and in the third method the capital was recovered gradually.

2.2.1 Appropriate Interest Rates for Public Investments

It is particularly appropriate to discuss the aspect of setting "reasonable" interest rates for the analysis of public investments. In this regard, the principles as stated in the Green Book for water resources are equally appropriate for highway or transport investments and can be summarized by two of its paragraphs:[44]

[44] Proposed Practices for Economic Analysis of River Basin Projects, Report to the Inter-Agency Committee on Water Resources, Washington, D.C., May 1958, p. 22 and 24.

> Prevailing interest and discount rates for loans and investments usually reflect both the "time" and "risk" elements. . . . It would be expected, however, that the total allowance for risk and interest appropriate in the analysis of a Federal project would be comparable with such allowance for private undertakings involving similar risk, uncertainty, and longevity.
>
> * * *
>
> . . .The minimum interest rate appropriate for use in project evaluation for converting estimates of benefits and costs to a common time basis is the risk-free return expected to be realized on capital invested in alternative uses. At a given time this rate is the projected average rate of return; i.e., yield, expected to prevail over the period of analysis, in the absence of inflationary or deflationary changes in the general price level, on such relatively risk-free investments as long-term government bonds. . . . If it is found impracticable or impossible to make the estimates of project effects on a risk-free basis, the risk allowance would have to be accounted for by an increment in the interest or discount rate applied to deferred effects.

The AASHO Red Book does not confront the subject as directly, but does imply a criterion for choosing interest rates in its examples; for instance, in one case it is noted that "... the prevailing local interest rate is 5 percent," a percentage figure that subsequently was used in the accompanying annual cost computations.[45] (In other numerical examples, the interest rates varied between 3. 5 and 6 percent.) Also, other comments in the AASHO Red Book are appropriate:[46]

> Reports of authoritative groups. . .support the inclusion of interest, <u>even on invested capital which is not borrowed money</u>. It seems conclusive that interest should be included in analyses regardless of the method of financing because interest will be charged if the highway agency borrows money or the money could be loaned with interest (being paid) if the highway agency has a cash surplus. In the latter case the loss of potential income would exactly balance the required payment in the first instance.

Hirshleifer et al recommend that the public and private sectors should use the same discount rate and argue that:[47]

> . . .The existence of a different (and lower) discount rate in the sphere of public as compared with private investment decisions is inefficient. . . . If a lower rate is used, public projects will be adopted where the capital could alternatively be used for purposes of private investment or consumption that are valued <u>more</u> highly by consumers.

Further, they suggest that 4 to 5 percent would be an appropriate riskless discount rate for government investments in this country, but that 10 percent would be more appro-

---

[45] AASHO Red Book, op. cit., p. 31.

[46] Ibid., p. 55.

[47] Jack Hirshleifer, James de Haven, and Jerome Milliman, Water Supply Economics, Technology, and Policy, University of Chicago Press, 1960, Chaps. 6 and 7.

priate for public water resources' investments if the discount rate is to reflect the risks of incorrectly estimating the project benefits and costs.[48]

A point of view similar to that of Hirshleifer et al has long been expressed by Grant and Winfrey, among others; in one writing, Grant noted:[49]

> . . . In general, the minimum attractive rate of return should never be less than the cost of money. Often, however, the minimum attractive rate of return should be considerably higher than the cost of money because of considerations related to the investment opportunities foregone. In the language of the professional economist, the concept of "opportunity cost" is applicable to the selection of the interest rate to be used in economy studies.

Also, on commenting about the specific interest rates which seem most appropriate (at the present time) for making economy studies, Grant says:[50]

> . . . To be specific, I suggest the use of a 7 percent figure; as already mentioned, this is the figure currently used in many economy studies for the regulated public utilities throughout the United States.

Winfrey makes the same point, but emphasizes the risk aspects more in stating:[51]

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

Richard Zettel comments on these matters as follows:[52]

> Because a large amount of highway financing in the United States is done on a "pay-as-you-go" basis (that is, without borrowing and without actual outlays for interest), some confusion has arisen regarding the computation of interest costs. Yet, when individual projects or variations of a specific improvement involve different sums and different periods for capital recovery any comparisons which exclude interest would be highly misleading. Quite obviously an "opportunity" cost should be attached to each possible use of the money since it will not be available for other purposes.
>
> The proper recognition of interest costs is even more important in appraising the economic costs of the highway programme as a whole. Here the decision involves the drawing of resources from all other pos-

---

[48] Ibid.

[49] E. L. Grant, Interest and the Rate of Return on Investments, HRB Special Report 56, p. 82-83.

[50] Ibid., p. 86.

[51] R. Winfrey, Concepts and Applications of Engineering Economy in the Highway Field, HRB Special Report 56, p. 22.

[52] Richard M. Zettel, Highway Benefit and Cost Analysis as an Aid to Investment Decision, Institute of Transportation and Traffic Engineering, University of California, Reprint No. 49.

> sible public and private uses. The funds so taken might have been invested in other productive endeavours in which case they would have yielded a return. Or they might have been taken from consumption channels in which case the people are required to forego immediate satisfactions and the time preference cost should be recognized.

Suffice it to say that we are in agreement with the above writers' views and feel that an interest rate must be used in a proper economy study and that it should be a realistic value. The fact that important public decisions are often made with very low interest rates (and sometimes with a zero interest rate) can only be a matter of concern for both engineers and economists.

2.3 PROBLEMS INVOLVING RISK AND UNCERTAINTY

With most investment or design situations, and where improvements require the expenditure of capital or operating funds, the designer or decision-maker usually must make decisions in the face of inherent uncertainties about the proposed project.[53] That is, in deciding whether to commit resources or funds, the designer must usually estimate or guess what the costs and benefits will be on an uncertain basis—either because of lack of information or because of certain unpredictable aspects; for example, benefits from highway construction may be dependent upon population growth, meteorological conditions, or other such variables whose future values cannot be predicted with complete accuracy or certainty. Thus the designer (or decision-maker) is forced to risk resource commitments against uncertain future gains. (Similarly, in not undertaking a project, some risks are taken by the designer or decision-maker.)

Problems involving "doubt" or "unpredictability" fall into two classes, definitionally, and generally are categorized as ones of either "risk" or "uncertainty." The distinction between the two terms is as follows:

1. Problems of risk are those whereby the future outcomes or consequences have a known probability of occurrence; thus while the chances of a particular outcome may be known, no assurance can be given of which particular outcome will take place.
2. Problems of uncertainty are those whereby even the probabilities of the future outcomes or consequences are unknown and whereby the probabilities can be determined only subjectively.

These distinctions are of vital importance in the matter of determining the specific probabilities of the various outcomes and consequences associated with different actions,[54] and thus in the matter of determining the level and character of benefits or costs to be anticipated in any particular year for any specific project. However, the matter of estimating these probabilities or a probability density (or mass) function, whether on some objective or on a subjective basis, will not be treated herein but will be left to the reader.[55] Further, in the following discussions of risk and uncertainty, no particular distinction will be made between the two terms, and the probabilities associated with various events[55] will be stated without regard for their determination; in so doing, no violence is done to the generality of the economic analysis techniques and to the methods and procedures for analyzing consequences, once the probabilities of their occurrence are known.

---

[53] Among a number of excellent references, see: Herman Chernoff and Lincoln Moses, Elementary Decision Theory, John Wiley and Sons, New York, 1959; Robert Schlaifer, Probability and Statistics for Business Decisions, McGraw-Hill Book Company, New York, 1959; and Duncan R. Luce and Howard Raiffa, Games and Decisions, John Wiley and Sons, New York, 1957.

[54] An action is simply an alternative design available to and subject to the control of the designer, while an event is a possible occurrence which can take place and which is beyond the control of the designer and is independent of the set of actions.

[55] See the previous references, for example.

TABLE 2.3

PROBABILITIES FOR EVENT x IN YEAR t

x	Event* x Occurring in Year t, Where t Is 4 $E_{x,t}$	Probability of Occurrence of Event x in Year t, Where t Is 4 $p(E_{x,t})$
1	$E_{1,4}$	0 17
2	$E_{2,4}$	0 39
3	$E_{3,4}$	0 28
4	$E_{4,4}$	0 16

$$\sum_{x=1}^{4} p(E_{x,t}) = 1\ 00$$

*These events could be regarded as, say, different levels of car ownership (and thus travel) in year t, providing of course that car ownership and travel are independent of the possible actions, which, say, are alternative roadway designs

TABLE 2.4

PAYOFF TABLE

($VP_{x,y,t}$), Value of Payoff* of Action ($A_{y,t}$) in Year t, Given the Occurrence of Event ($E_{x,t}$), Where t Is 4

Event	Action				
	$A_{0,4}$	$A_{1,4}$	$A_{2,4}$	$A_{3,4}$	$A_{4,4}$
$E_{1,4}$	0	$5 84	$6 60	$6 50	$5 70
$E_{2,4}$	0	7 15	6 80	6 65	6 40
$E_{3,4}$	0	7 40	7.45	7 80	7 65
$E_{4,4}$	0	9 00	8 30	8.75	9 15

*For purposes of the example, assume these payoff values to be net revenues, in $ millions, also, action $A_{0,4}$ refers to "no action," or the null alternative

To illustrate the general principles consider the example shown in Tables 2.3 and 2.4, wherein the payoff or net revenue (gross annual revenues minus gross annual costs) to be derived from alternative toll-road projects (or, no project at all) in year t after its opening is determined; in determining the net revenue, we wish to account for the rather uncertain nature of the economy as it affects income, car ownership, and in turn travel and toll revenues.

Table 2.3 includes the probabilities of occurrence of each event which affects the outcome or consequences for the actions being analyzed; these probabilities can in turn be applied to the values included in the payoff table, Table 2.4, to determine the expected value of each of the set of proposed actions to be analyzed. (A payoff table merely shows the values which each action can be expected to "pay off," given a particular event; Schlaifer describes it as a table which shows the conditional values, or values of each and every action given each and every event.)[56]

These probabilities and prospective net revenues or payoffs can be integrated to provide an estimate of the most probable or expected net revenue of action y in year t. This last step is carried out in Table 2.5, wherein $p(E_{x,t})$, the probability of event x occurring in year t, is multiplied times $VP_{x,y,t}$ (the payoff of action $A_{y,t}$, action y at year t, given the occurrence of event $E_{x,t}$) and summed over all n possible events for action y.

Thus:

$$\text{Expected value of action y in year t} = \sum_{x=1}^{n} p(E_{x,t})\,(VP_{x,y,t}) \tag{2.1}$$

where

$p(E_{x,t})$ = probability of event x occurring in year t, and

$VP_{x,y,t}$ = value of payoff of action $A_{y,t}$ in year t, given the occurrence of event $E_{x,t}$.

It is important to clarify the meaning and usefulness of these expected value figures, for there is considerable latitude in their application. In a situation where the sole criterion for measuring value, efficiency, and "goodness" is maximization of the expected or most probable payoff value of actions and events, it is clear that for our

[56]Schlaifer, op. cit., p. 25.

TABLE 2.5

EXPECTED VALUE OF ACTIONS*

Action y in Year t (where t is 4)	Expected Value** of Action y in Year t (where t is 4, $ millions)
$A_{0,4}$	$0.000
$A_{1,4}$	7.295
$A_{2,4}$	7.188
$A_{3,4}$	7.282
$A_{4,4}$	7.071

*Based on data in Tables 2.3 and 2.4; also, expected value is used herein in the sense of "weighted average" value.

**Expected value of action y in year t $= \sum_{x=i}^{n} p(E_{x,t})(VP_{x,y,t})$

example of five actions or alternatives, the $A_{1,4}$ action would be preferable if these were the only data available. However, inasmuch as the expected values in Table 2.5 are only for a single year (year 4), as the capital costs are not necessarily accounted for, and as no discounting of the future expected values has been accomplished, no firm conclusion or finding can be made regarding the best or preferred action, even in the instance where the sole criterion was maximization of the expected payoff value. In short, a complete analysis must include expected value data for all other years in the analysis period, in addition to the initial capital costs, all of which must be discounted properly.

Even with all payoff value and cost items included in our totals and even with proper discounting, the action or alternative with highest expected payoff value may not necessarily be regarded as the best or preferred action. For example, it would be entirely proper for those risking the investment funds to select other criteria as more appropriate for their purposes. For example, the best action alternative might be selected on the basis of comparing the lowest possible payoff of each of the actions and choosing that action having a minimum payoff which is larger than the minimums of the other actions (the so-called MAXIMIN solution). Another decision-rule might call for selecting that action or alternative offering the largest possible payoff (or so-called MAXIMAX solution).

From Table 2.4, the action to be selected with a MAXIMIN decision-rule would be $A_{2,4}$ and that to be selected with a MAXIMAX decision-rule would be $A_{4,4}$. For these data, both of these decisions would be different from the action selected by the maximum expected payoff rule.

Finally, in this brief introduction to the subject of uncertainty (and even more superficially that of decision-making), it should be emphasized that our intention was not to cover the subject appropriately but merely to indicate the nature of the subject and to note how it might be applied to help reflect uncertain or unpredictable events.

2.4 METHODS OF ECONOMIC ANALYSIS

Each of the four principal techniques for analyzing highway and transport investments (annual cost, benefit-cost ratio, rate-of-return, and net present value) will be described both qualitatively and analytically, and will be compared and evaluated in terms of their validity, strengths, and weaknesses.

For these purposes, we first define a set of symbols which pertain to the total (allowable) costs and benefits associated with any particular system or project. (See

Table 1.1 and related sections in Chapter 1.) The items of cost associated with a project or alternative are as follows:

$CFC_{y,t}$ = capital costs (for project y in year t) for facility (roadway) construction, land acquisition, social dislocation, and the like;

$CFO_{y,t}$ = continuing costs for facility operation and maintenance costs (for project y in year t);

$CVC_{y,t}$ = capital costs for vehicles and their terminal facilities (for project y in year t);

$CUT_{y,t}$ = continuing travel time, discomfort, and inconvenience costs for users (for project y in year t); and

$CVO_{y,t}$ = continuing costs for user vehicles and terminal facility maintenance and operation (for project y in year t).

Similarly, the items of benefit associated with a project or alternative are the following:

$BUN_{y,t}$ = non-perceived user travel value or benefit received by users from tripmaking (for project y in year t);

$BUM_{y,t}$ = perceived user travel benefit received by users from tripmaking (for project y in year t); and

$BOM_{y,t}$ = other non-user revenues received as a result of project y (in year t), such as intergovernmental transfers or concession revenue.

At the outset it must be stressed that each of these methods of economic analysis in one way or another has associated with it an interest rate and a period of analysis.[57]

2.4.1 Annual Cost Method

With the annual cost method, the capital costs generally are placed on an equivalent annual basis (to include principal and interest)[58] and then added to the continuing facility and user operating and travel costs, after the travel volume has been placed on an equivalent annual basis. (This latter aspect is handled in Chapter 3).

Money payments in different years are placed on a proper time basis by the inclusion of interest (foregone) on capital. Once all alternative projects, to include the null or do-nothing possibility, have been analyzed and their annual costs computed, the project of lowest total annual cost is selected as the most desirable—everything else being equal.

Analytically, the annual cost method may be expressed as follows:[59]

$$\left[TAC_{y,\bar{t}}\right]_i = (crf_{i,n_F})(CFC_{y,o}) + CFO_{y,\bar{t}} + (crf_{i,n_V})(CVC_{y,o}) + CVO_{y,\bar{t}} + CUT_{y,\bar{t}} \quad (2.2)$$

where

$\left[TAC_{y,\bar{t}}\right]_i$ = Equivalent annual costs for project y during the $\bar{t}$th year, using an interest rate of i;

n = service life of facility (or period of analysis);

---

[57]Other terms for interest rate are discount rate, and opportunity cost of capital.

[58]This would be done in much the same fashion as a bank handling a home mortgage; obviously, it is necessary to specify an interest rate (or set of interest rates).

[59]This formulation, one common to highway engineering literature, assumes implicitly that the capital costs are initially committed in year 0 (i.e., at the present) and are replaced periodicially at the end of their service lives.

$\bar{t}$ = representative year during the service life n or that year having "equivalent annual" costs;
n_F = service (or replacement) life for facility capital items;
n_V = service life for vehicle capital items; and
$crf_{i,n}$ = capital recovery factor at an interest rate of i and for a life of n_x; computed as shown in Table 2.6.

In applying this method, both the facility and vehicle capital costs should be treated separately, by item, in those cases where the service lives vary (such as for right-of-way and structures). Also, this formulation at least suggests that automobile ownership costs should be treated as any other capital cost, rather than handled as a variable or per vehicle-mile cost.

It should be noted that benefits are not considered in the annual cost method. Since any investment accrues benefits which are of concern to the investor, a decision made without consideration of the benefits invariably assumes that the benefits from each alternative investment project are the same. In other words, so long as the benefits to be achieved from the various projects are identical, the cheapest project will be best. However, in the more usual or typical case where volume will increase as the traffic service improves (particularly so long as the present-day user gas and excise tax policies continue), neither the volumes nor benefits for alternative projects will be equal; thus the total annual cost method can give incorrect results and lead to improper decisions. Since the conditions under which the annual cost method gives correct results would appear to be remote, this method is ruled out as a general economic analysis tool.

2.4.2 Benefit-Cost Ratio Method

The benefit-cost ratio method (which sometimes is called the cost-benefit method, as by Charlesworth of the English Road Research Laboratory) has been defined in various ways, and thus has been confused in practice. When comparing two projects, the associated benefit-cost ratio could appropriately be defined as the ratio of the additional benefits achieved by the more costly project to the additional capital and continuing costs incurred for the more costly project, all costs and benefits being placed

TABLE 2.6

CAPITAL RECOVERY FACTORS FOR CERTAIN SERVICE LIVES AND INTEREST (OR DISCOUNT) RATES*

Service Life (years)	Percent							
	0	2	3	4	5	6	8	10
5	0.20000	0.21216	0.21835	0.22463	0.23097	0.23740	0.25046	0.26380
10	0.10000	0.11133	0.11723	0.12329	0.12950	0.13587	0.14903	0.16275
15	0.06666	0.07783	0.08377	0.08994	0.09634	0.10296	0.11683	0.13147
20	0.05000	0.06116	0.06722	0.07358	0.08024	0.08718	0.10185	0.11746
25	0.04000	0.05122	0.05743	0.06401	0.07095	0.07823	0.09368	0.11017
30	0.03333	0.04465	0.05102	0.05783	0.06505	0.07265	0.08883	0.10608
35	0.02857	0.04000	0.04654	0.05358	0.06107	0.06897	0.08580	0.10369
40	0.02500	0.03656	0.04326	0.05052	0.05828	0.06646	0.08386	0.10226
45	0.22222	0.03391	0.04079	0.04826	0.05626	0.06470	0.08259	0.10139
50	0.02000	0.03182	0.03887	0.04655	0.05478	0.06344	0.08174	0.10086
60	0.01666	0.02877	0.03613	0.04420	0.05283	0.06188	0.08080	0.10033
80	0.01250	0.02516	0.03311	0.04181	0.05103	0.06057	0.08017	0.10005
100	0.01000	0.02320	0.03165	0.04081	0.05038	0.06018	0.08004	0.10001

*Computed from: $crf_{i,n} = \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$

on an equivalent annual basis.[60] (As in the annual cost method, it is necessary to specify the discount rate or rates.) Generally, the interest rate is defined as the opportunity cost of capital or minimum attractive return on capital, and thus no expense or increment of expense will be made which has a benefit-cost ratio of less than one (1.0).

Analytically, the highway engineer's definition of the benefit-cost ratio may be expressed as:

$$\left[BCR_{jk,\bar{t}}\right]_i = \frac{(BUN_{j,\bar{t}} + BUM_{j,\bar{t}} + BOM_{j,\bar{t}}) - (BUN_{k,\bar{t}} + BUM_{k,\bar{t}} + BOM_{k,\bar{t}})}{\left[TAC_{j,\bar{t}}\right]_i - \left[TAC_{k,\bar{t}}\right]_i}, \qquad (2.3)$$

where

$\left[BCR_{jk,\bar{t}}\right]_i$ = benefit-cost ratio of project j as compared to project k, using equivalent annual costs and benefits for the $\bar{t}$th year and an interest rate of i.

For simplicity, let

$\left[TAB_{y,\bar{t}}\right]_i$ = equivalent annual benefits for project y for the $\bar{t}$th year at a discount rate of i.

then

$$\left[BCR_{jk,\bar{t}}\right]_i = \frac{\left[TAB_{j,\bar{t}}\right]_i - \left[TAB_{k,\bar{t}}\right]_i}{\left[TAC_{j,\bar{t}}\right]_i - \left[TAC_{k,\bar{t}}\right]_i}$$

This formulation of the benefit-cost ratio is different from that sometimes appearing in the highway engineering literature; specifically, many highway engineers include only reductions in user costs as benefits in the numerator, and restrict the denominator to differences between highway costs (capital and operating).

The highway engineer's definition of the benefit-cost ratio differs from that of the economist in some important respects. According to the economist, benefit-cost ratios are first computed for each overall project. Second, incremental benefit-cost ratios are computed for the incremental effects of increasingly higher cost projects. Third, the economist usually computes these ratios on the basis of discounted rather than equivalent annual costs and benefits; however, it should be noted that these ratios will be identical regardless of whether one uses discounted or equivalent annual costs and benefits.

Using equivalent annual costs and benefits, the benefit-cost ratio for a single project (say, the j th project) would be:

$$\left[BCR_{j,\bar{t}}\right]_i = \frac{(BUN_{j,\bar{t}} + BUM_{j,\bar{t}} + BOM_{j,\bar{t}})}{\left[TAC_{j,\bar{t}}\right]_i} \qquad (2.4)$$

The ratio shown in Eq. 2.4 will permit evaluation of overall projects, and that shown in Eq. 2.3 will permit evaluation of incremental effects.

To determine the economic feasibility of projects, the benefit-cost ratio should first be computed using Eq. 2.4 for the lowest cost project and then for each alternative of

---

[60] This definition is common to highway engineering practice; e.g., see AASHO Red Book and Oglesby and Hewes textbook. However, the inclusion of differences in continuing costs in the denominator is in contrast to the procedure outlined by Maass, op. cit., p. 33 ff.

increasingly higher cost. All projects which demonstrate a benefit-cost ratio equal to or greater than one can be regarded as suitable, economically, and will provide economic returns at least as high as the discount rate (which presumably was set at the opportunity cost of capital or minimum attractive return).

Determining the best alternative, though, also requires computation of the benefit-cost ratio associated with increments of expenditure for increasingly higher cost projects which satisfied the first test; Eq. 2.3 can be used for computing these incremental benefit-cost ratios. Once the benefit-cost ratios for both the entire expenditure and increments of expenditure have been computed, that project of highest cost whose overall and incremental benefit-cost ratios are both equal to or greater than one will be selected as the most desirable or economic.

2.4.3 Rate of Return Method

In recent years the rate-of-return method has received much attention in the highway engineering economy literature and has contributed greatly to the quality of economic analyses.

The economist would define the rate of return as "that rate of discount which reduces a stream of cash flows to zero,"[61] or as "the rate of interest at which the present value of expected capital outlays is exactly equal to the present value of expected cash earnings on that project."[62] Placing this in a general benefit and cost context, the rate-of-return would be that discount or interest rate at which the present value of both present and future benefits is just equal to the present value of both present and future costs.

An engineer, by contrast, might define rate-of-return differently, and state that "the rate-of-return method involves finding the interest rate at which two alternative solutions to an economy problem have equal annual costs or present worths. The first step is to find the rate of return on each proposed investment as compared with the solution that requires the least capital outlay, which often is the status quo. . . . Next the rate of return is computed on the increase in investment between proposals having successively higher first costs."[63]

There are important differences between the rate-of-return method as applied by the economist and that applied by the engineer; these will be explained in detail later in this section. Furthermore, the techniques as outlined by the engineer are not sufficiently generalized to apply to all cases, but appear to apply only because of specialized assumptions used in the examples to demonstrate the method.

There are two ways of computing r, the rate-of-return.

1. Equivalent annual benefit and cost procedure: the rate-of-return, r, for project y is that discount rate which will satisfy the following equality:[64]

$$TAC_{y,\bar{t}} = TAB_{y,\bar{t}} \qquad (2.5)$$

or

$$(crf_{r,n_F})(CFC_{y,o}) + CFO_{y,\bar{t}} + (crf_{r,n_V})(CVC_{y,o}) + CVO_{y,\bar{t}} + CUT_{y,\bar{t}} = BUN_{y,\bar{t}} + BUM_{y,\bar{t}} + BOM_{y,\bar{t}} \qquad (2.6)$$

---

[61] Lorie and Savage, op. cit., p. 63. E. L. Grant uses a similar definition.

[62] Solomon, op. cit., p. 74.

[63] Clarkson Oglesby and L. Hewes, Highway Engineering, John Wiley & Sons, New York, 2nd Edition, 1963, p. 86. However, we would interpret "capital outlay" and "investment" more broadly and would include all cash expenditures over the analysis period.

[64] Eq. 2.6 applies, as written, only for the case when the initial capital costs $CFC_{y,o}$ and $CVC_{y,o}$ are made during year 0 (i.e., when t = 0) and assumes periodic replacement. Eq. 2.7, however, is valid in all cases.

2. Discounted benefit and cost procedure: the rate-of-return, r, for project y is that discount rate at which the present value of all expected costs just equals the present value of all expected benefits, and is the interest rate which satisfies the following equation:

$$\sum_{t=0}^{n} (pwf'_{r,t}) (CFC_{y,t} + CFO_{y,t} + CVC_{y,t} + CVO_{y,t} + CUT_{y,t}) =$$

$$\sum_{t=0}^{n} (pwf'_{r,t}) (BUN_{y,t} + BUM_{y,t} + BOM_{y,t}) \qquad (2.7)$$

where $pwf'_{r,t}$ is the present worth factor as defined earlier, and n is the period of analysis. (Sometimes n is assumed to be equal to the least common multiple of the service lives of the projects being compared, or to be equal to the longest service life of any capital item of all projects being analyzed.)

While either of these two procedures for determining the rate-of-return is correct, the latter seems more useful and simpler in actually carrying out the analysis. In any further discussion, the discounted benefit-cost procedure will be considered to be common practice, as it usually is among economists.

In choosing among alternatives, each alternative having a rate-of-return at least equal to the minimum attractive return or (opportunity) cost of capital can be regarded as acceptable. However, those "alternatives which require greater investment (than the smallest investment alternative which is acceptably profitable) are preferable to this (smaller) one only if the added investment over this (smaller) amount produces enough added earnings to yield a satisfactory rate-of-return."[65]

Perhaps a clearer explanation of the decision-making criteria for the rate-of-return method is given by Lorie and Savage:[66]

> 1. Compute the rate of return for that investment proposal, among the set of mutually exclusive proposals, requiring the least initial net outlay.
> 2. If the rate of return on the investment requiring the smallest outlay exceeds the firms' cost of capital (or other cutoff rate), tentatively accept that investment. Next compute the rate of return on the incremental outlay needed for the investment requiring the second lowest outlay. If that rate exceeds the firm's cutoff rate, accept the investment requiring the greater outlay in preference to that requiring the lesser. Proceed by such paired comparisons (based on rates of return on incremental outlay) to eliminate all but one investment.
> 3. If the rate of return on the proposal requiring the least outlay does not exceed the firm's cutoff rate, drop it from further consideration, and compute the rate of return for the proposal requiring the next least outlay. If that rate exceeds the firm's cutoff rate, that investment proposal becomes the bench mark for the first paired comparison. If that rate does not exceed the firm's cutoff rate, drop that proposal from further consideration. The process just described is to be repeated until either a proposal is found with a rate of return exceeding the cost of capital or until all proposals have been eliminated because their rates of return do not exceed the cutoff rate.

---

[65] Joel Dean, Measuring the Productivity of Capital, in The Management of Corporate Capital, ed. by Ezra Solomon, Free Press of Glencoe, 1959, p. 28.

[66] Lorie and Savage, op. cit., p. 65-66.

This interpretation of the rate-of-return method differs from that often used by the engineer (and as described in the third paragraph of this section). More specifically, the engineer often notes that "... the first step is to find the rate-of-return on each proposed investment as compared with the solution that requires the least capital outlay, which often is the status quo."[67] This latter usage differs markedly from that of the economist and if strictly adhered to would not require analysis of the rate-of-return for the lowest cost alternative (whether it be an existing facility or the lowest cost entirely new project). Obviously, this implies that neither the existing facility nor the lowest cost new project (if there is no existing facility) can be abandoned and it implies that the lowest cost alternative is always economically feasible. Clearly, these assumptions are not always valid and, therefore, the engineer's interpretation must be rejected in favor of that of the economist.

2.4.4 Net Present Value Method

With the net present value (or, net present worth) method, present and future costs and benefits are discounted to the present and summed and the difference between the two sums computed; the appropriate opportunity cost of capital or minimum attractive return is used to set the interest rate for discounting the future cost and benefit streams.

$$\begin{aligned} \text{Net present value} &= \text{sum of discounted benefits minus} \\ &\quad\ \text{sum of discounted costs} \\ &= \sum_{t=0}^{n} (pwf'_{i,t})\,(BUN_{y,t} + BUM_{y,t} + BOM_{y,t}) \\ &\quad - \sum_{t=0}^{n} (pwf'_{i,t})\,(CFC_{y,t} + CFO_{y,t} + CVC_{y,t} \\ &\quad + CVO_{y,t} + CUT_{y,t}) \end{aligned} \tag{2.8}$$

where n is the period of analysis.

No project having a net present value less than zero is acceptable with this analysis method, and that project of highest net present value will be most desirable when choosing among mutually exclusive alternatives.

Perhaps it is useful to note that when analyzing only the incremental effects of changing one design detail or the other (such as the pavement design) and when the benefits will remain unchanged use of the net present value method will be exactly equivalent to the annual cost method in choosing the best design. However, for the task of answering the question "Why do it at all?" both the benefit and cost data are required.

2.5 SALVAGE VALUE AND TERMINAL DATE OR SERVICE LIFE PROBLEMS

Two other special characteristics of economic analysis methods deserve particular attention; namely, the treatment of salvage value and treatment of the analysis period.

Alternative investments can only be properly compared by examining the circumstances of cost and benefit over the same time period or time span.[68] Briefly, if short and long life investments are being compared, the economic analysis is not complete unless it also considers the investment and income possibilities once the shorter life project is terminated (since the longer life project still continues and therefore may continue to produce income).[69] This problem of differing terminal dates or service lives may be handled in a number of ways.

---

[67] Oglesby and Hewes, op. cit., p. 86.

[68] An excellent reference is Solomon, op. cit., p. 74 ff. Also, see Grant and Ireson, op. cit., Ch. 16.

[69] Also, it is necessary to consider the reinvestment possibilities for earnings generated during the various investment periods; this aspect will be covered in a later example.

First, it may be assumed that the projects will be perpetual and thus that the facility will be renewed and replaced periodically (according to the assumed service lives). While this assumption may be a convenient one, it hardly appears to be entirely valid. In any case, if this assumption is made, it should be so stated explicitly.

Second, the analysis may also be handled by analyzing the costs and benefits over a time period equal to the "least common multiple" of the lives of the projects being analyzed.[70] During the time period all items of capital with service lives shorter than the time period are renewed according to their respective service lives. The advantage of this method of handling the problem is simply that it eliminates the necessity of dealing with salvage values; that is, the end of the analysis or terminal date corresponds to a date where the capital of all projects is fully depreciated and (presumably) has no salvage value.

Third, one may select as the time period of analysis (or service life or terminal date) the service life of the project of longest life and may use this time period for analyzing all projects. However, in this case it may be necessary to account for the salvage value of some capital items and it will be necessary to take account of the investment possibilities for capital recovered from non-renewable projects of shorter life than the terminal date.

A final possibility is simply that any arbitrary time period of analysis may be selected and that all cost and income circumstances (including salvage and reinvestment of earnings) are properly accounted for all projects during that period.

Salvage values can be incorporated into any of the techniques. For the methods which use discounted costs and benefits (either net present value method or the rate-of-return method), an additional negative term must be added to the cost side of the equation as follows:

$$\text{Discounted salvage value} = \sum_{x=1}^{m} (\text{pwf}'_{i,n})(S_{y,x}) \tag{2.9}$$

where

$S_{y,x}$ = salvage value of the x th capital item of project y at the terminal date (n years) and interest i; and

m = number of capital items of project y having a salvage value in the n th year.

For those methods using equivalent annual costs and benefits, the negative cost term will be:

$$\text{Salvage value} = \sum_{x=1}^{m} (\text{sff}_{i,n})(S_{y,x}) \tag{2.10}$$

where

$\text{sff}_{i,n}$ = sinking fund factor[71] at interest i and at n th year

$$= \frac{i}{(1+i)^n - 1} \tag{2.11}$$

2.6 CRITIQUE OF ECONOMIC ANALYSIS METHODS

We would remind the reader that our concern is with the problem of choosing among mutually exclusive alternative projects, and thus with choosing just one project from a number of alternative ways of accomplishing the same general task. (Note further that one possible alternative is always to continue using the existing alternative, no

---

[70] Grant and Ireson note this (p. 100), but restrict definition of the least common multiple of the lives to the two alternatives being compared; in general, all those mutually exclusive projects being considered and compared should be included in figuring the least common multiple.

[71] See Grant and Ireson, op. cit., p. 45.

matter how bad or inconvenient it may be; in other words, the null or do nothing alternative must always be included among the set of alternatives being analyzed.[72]

The four principal economic analysis methods for choosing among alternatives were described in the previous section; we shall endeavor to compare and evaluate these techniques, noting both the difficulties with regard to economic principles and computation.

The annual cost method is all but neglected in this presentation as an appropriate economic analysis method since it fails to apply when the benefits of the alternatives being analyzed and compared are not identical; this almost always will occur when the user volumes for alternatives are not equal. Since any two alternatives being compared almost always will have both cost and benefit streams that differ, the annual cost method can hardly be judged a practical or suitable analysis technique. These discrepancies will be highlighted in the example problem in Chapter 3.

The benefit-cost ratio method of analyzing proposals is less than desirable for three major reasons:[73]

1. It is not used on any widespread basis nor is it well understood by other than water resources and highway engineering personnel—thus, when presenting the economic analysis results to decision-makers or policy-makers, who more often than not will be unfamiliar with benefit-cost ratio techniques and their meaning, some considerable lack of understanding may occur;
2. The benefit-cost ratio, by itself, has little significance and its relative value therefore is difficult to understand and interpret—in other words, the difference between two proposals having ratios of 1.05 and 1.10 is difficult to grasp, and can hardly be understood as readily as differences between alternatives can be judged when using discount rates or rates-of-return;
3. The benefit-cost ratio is arbitrary with respect to whether cost reductions or savings should be called benefits or negative costs, and with respect to whether highway maintenance cost reductions should be included in the denominator or numerator, and so forth.

Since most of these objections do not apply to the present value or rate-of-return techniques, in our judgment the benefit-cost ratio method should be rejected in favor of either the rate-of-return or net present value methods.

The differences between the net present value and rate-of-return methods of economic analysis, in terms of suitability and unambiguity, are subtle and not well understood; they relate mainly to aspects which usually have been explored and understood only by the economist and which are not usually reported in engineering literature.[74]

First, in a comparison between the net present value and rate-of-return methods, it can be said that the net present value method will always give correct economic decision-making answers or results while in some situations the rate-of-return method can give ambiguous answers.[75]

---

[72] Where no system or facility is in existence, the null still exists in the sense that no capital outlays are required and no earnings will be forthcoming (i.e., the net present value will be zero over n years). Thus if the estimated net present value for all proposed alternatives is less than zero (or negative), then the best alternative would be the null; that is, do nothing.

[73] For a full discussion of the technical difficulties associated with this method and its many applications, see: Roland McKean, Efficiency in Government Through System Analysis, John Wiley and Sons, New York, 1958, Ch. 7.

[74] Particularly appropriate are the aforementioned articles by Solomon, op. cit., and Lorie and Savage, op. cit., and the text by Bierman and Smidt, op. cit.

[75] One problem arises, for example, in situations when increases in the discount rate do not produce steadily decreasing present values for certain proposals; while these situations would not appear to be typical or even relatively frequently occurring on highway projects, Lorie and Savage at least point out that this situation can occur and as a consequence can provide multiple rates-of-return and hence ambiguous results.

An additional advantage of the net present value method is that all costs and benefits are stated in present-day terms and thus are uninflated by interest costs to be accrued in the future. For example, consider the present value (that is, real money requirements measured in present-day dollars) of a system which will require $100 million to be spent in equal amounts, year by year over the next ten years;[76] in such a case, the present value and more realistic present-day cost to be considered would be $73.6 million, assuming a 6 percent discount rate. It would be $61.44 million with a 10 percent interest rate. In short, balanced against present-day values and comparative costs, the $100 million cash flow costs would appear inflated to the decision-maker.[77]

However, the rate-of-return does have the distinct advantage of being easier to understand and of being more widely understood, at least by the business world since it is equivalent to familiar business terms and concepts such as "effective yield" and "internal rate of profit."

An important computational advantage of the net present value method, as compared to the rate-of-return type of analysis, is that the present value of increments of investment between successively higher investments can be determined simply by inspecting the net present value of the investments themselves. If the net present value either stays the same or increases as the investment increases, then the net present value of the increment of investment must be equal to or greater than zero and thus must be acceptable. Consequently, no added computations are necessary beyond the calculation of net present values for the alternatives. However, with the rate-of-return method, one cannot be sure that the rate-of-return to be obtained from increments of investment will be equal to or greater than the cost of capital without actually carrying out the additional computations, or without examining the net present value data. Thus, greater computational difficulties will be encountered in using the rate-of-return method as compared to the net present value method.

More importantly, though, the rate-of-return will not necessarily provide correct results and answers (as will the net present value method) for choosing among mutually exclusive projects which have different lives or terminal dates unless the rates-of-return for all alternatives are calculated on the equivalent yield over the same time period of analysis applied to all alternatives, and unless the re-investment of earnings generated during the period of analysis is properly accounted for.[78] The importance of these points cannot be overstated.

The ambiguity will depend on the assumptions regarding reinvestment of funds which are recovered prior to the end of the time period of analysis. The problem arises because reinvestment aspects are generally handled implicitly and because the two analysis techniques treat reinvestment in different ways in the absence of explicit recognition being made about reinvestment. Indeed, Solomon has noted that,[79] "If a common assumption is adopted [about the reinvestment rate for funds freed prior to the end of the time period of analysis], both approaches will always rank projects identically."

The problem involves the use of earnings which are released prior to the end of the analysis period. For example, are they reinvested at the cost of capital, or are they reinvested in some other project having a rate-of-return different than that of the initial project? If no explicit mention is made of the reinvestment rate, the adoption of the rate-of-return or net present value criteria would imply that the following assumptions were made with respect to the reinvestment rate:

1. Rate-of-Return. To use the rate-of-return criterion is to assume in certain cases that the reinvestment rate for all earnings or funds freed prior to the terminal

---

[76] For simplicity, assume that the first payment is to be made at the end of one year from present, and each payment thereafter will follow the previous one by exactly one year.

[77] Certainly the discounted rate-of-return procedure (outlined in Section 2.4.3) also deals with uninflated costs and benefits, though the analyst seldom presents the discounted figures to the decision-maker.

[78] Grant and Ireson make the former point in Example 8-6, op. cit., but a more lengthy discussion of both points can be found in Solomon, op. cit., p. 75-77, and in Bierman and Smidt, op. cit., Ch. 3.

[79] Solomon, op. cit., p. 76.

date of the longer-lived project will be higher than the cost of capital. For example, for a project having a higher rate-of-return but a lower net present value than the next best one, use of the rate-of-return criterion is to assume that the reinvestment rate will be high enough to increase the net present value of the project of highest rate-of-return up to the level of the project having the highest net present value.

In the absence of an explicit statement to this effect, there would be every reason to regard the above assumption as invalid. Furthermore, the computation of the rate-of-return for a project of life L implicitly assumes that the reinvestment of earnings produced prior to the end of that life are reinvested at a rate equal to that same rate-of-return for the remainder of time during the life L. For example, for a project having a 10-year life and rate-of-return of 12 percent, this method implicitly assumes that earnings produced at the end of year 4 (say) would be reinvested at the rate of 12 percent per annum for the remaining 6 years. Clearly, there is no particular reason to suspect that the project rate-of-return and the reinvestment earnings rate should be equal.

2. Net Present Value. "The [net] present-value approach, as usually defined, assumes that the funds obtained from either project can be reinvested at a rate equal to the company's present cost of capital. . . ."[80]

In summary, the correct use of the net present value and rate-of-return methods has been stated by Solomon as follows:[81]

> Our conclusion is that correct and consistent ranking of the investment worth of competing proposals can be obtained only if the following factors are taken into account:
>
> 1. The valid comparison is not simply between two projects but between two alternative courses of action. The ultimate criterion is the total wealth that the investor can expect from each alternative by the terminal date of the longer-lived project. In order to make a fair comparison, an explicit and common assumption must be made regarding the rate at which funds released by either project can be reinvested up to the terminal date.
> 2. If the rate of return is to be used as an index of relative profitability, then the relevant rate is the per annum yield promised by each alternative course of action from its inception to a common terminal date in the future (usually the terminal date of the longer-lived project).
> 3. If the [net] present value is to be used as an index of relative profitability, the expected reinvestment rate or set of rates should be used as the discounting factor. These rates will be equal to the company's present cost of capital only by coincidence. [Emphasis added.]

That the two analysis methods can give conflicting results can be illustrated by examining two numerical examples given in Tables 2. 7 and 2. 8. In Table 2. 7, assume that the analyst is choosing among two (mutually exclusive) alternative projects, one having a 10-year life and capital outlay of $400, 000, and the second having a 30-year life and a capital outlay of $1 million; also, the discount rate or (opportunity) cost of capital is assumed to be 6 percent, both at present and in the foreseeable future. In Table 2. 8, two projects of equal capital outlay but with different service lives or terminal dates are compared.

In the comparison of projects A and B (Table 2. 7), project B would be judged as the best alternative of the two according to both the rate-of-return and net present value methods. While the 7 percent rate-of-return for project A is higher than the 6. 5 percent rate-of-return for project B, we must recall that both projects have a return

---

[80] Solomon, op. cit., p. 76.

[81] Solomon, op. cit., p. 77.

TABLE 2.7

COMPARISON OF (MUTUALLY EXCLUSIVE) PROJECT ALTERNATIVES HAVING DIFFERENT SERVICE LIVES AND CAPITAL OUTLAYS

Item	Project Alternatives*	
	A	B
Project service life (or terminal date of project)	10 years	30 years
Capital outlays at year 0	$400,000	$1,000,000
(Opportunity) cost of capital	6 percent per annum	6 percent per annum
Annual project earnings at end of each year till project terminal date**	$56,951 (per year for 10 years)	$76,577 (per year for 30 years)
Net present value† (at cost of capital) during project life	$19,159 (for 10-yr costs and earnings)	$54,082 (for 30 yr costs and earnings)
Rate-of-return††	7.0 percent over 10 years	6.5 percent ove 30 years

*It should be evident that the net present value of the additional capital outlay required by project B (over project A) is greater than zero, since the net present value for B is higher than that for A. And, the return on this additional outlay must be greater than the cost of capital, for the same reason.

**For project A, terminal date is 10 years hence, for B, it is 30 years.

†Discounted earnings minus discounted costs over service life, salvage value at end of service life assumed to be zero.

††Sometimes called the "internal rate-of-return" or "discounted rate-of-return." Also, the rate-of-return figure shown, and as normally calculated, assumes that the earn ings are reinvested at an equal rate during the remainder of the project life.

TABLE 2.8

COMPARISON OF (MUTUALLY EXCLUSIVE) PROJECT ALTERNATIVES HAVING DIFFERENT SERVICE LIVES BUT EQUAL CAPITAL OUTLAYS

Item	Project Alternatives	
	B	C
Project service life (or terminal date of project)	30 years	10 years
Capital outlays at year 0	$1,000,000	$1,000,000
(Opportunity) cost of capital	6 percent per annum	6 percent per annum
Annual project earnings at end of each year till project terminal date*	$76,577 (per year for 30 years)	$142,377 (per year for 10 years)
Net present value** (at cost of capital) during project life	$54,082 (for 30-yr costs and earnings)	$47,895 (for 10-yr costs and earnings)
Rate-of-return†	6.5 percent over 30 years	7.0 percent over 10 years

*For project B, terminal date is 30 years hence, for C, it is 10 years.

**Discounted earnings minus discounted costs over service life; salvage value at end of service life assumed to be zero.

†The rate-of-return figure shown, and as normally computed, assumes that the earnings are reinvested at an equal rate during the remainder of the project life.

that is at least as high as the cost of capital and that the additional capital or investment required by project B has a return that is higher than the cost of capital; thus, in spite of a lower overall rate-of-return, project B with its higher capital outlay must be judged the superior investment (according to the criteria outlined earlier).

Even though both the rate-of-return and net present value criteria indicated that alternative B was the best of the two projects, it must be emphasized that the set of underlying reinvestment assumptions was conflicting. To be specific, let us examine the circumstances for project A. For this project, the net present value method implies that the annual earnings when reinvested earn 6 percent, not only during the remaining years of the 10-year project life but thereafter as well; thus, the net present value at the end of either 10 or 30 years will be $19,159. However, for the rate-of-return method, it is implied that the annual earnings which are accrued prior to the end of the 10-year project life are reinvested at a reinvestment rate of 7 percent until the end of the project life, an assumption which clearly conflicts with the 6 percent reinvestment rate used for computing the net present value for the 10-year project. Obviously, the same reinvestment assumption should be used for computing both sets of values; thus, either the net present value should be increased to reflect an assumed 7 percent rate of reinvestment or the rate-of-return should be decreased to account for the fact that the reinvestment rate was only 6 percent. Analysts seldom make the necessary calculations to account for these reinvestment differentials, thus permitting situations to develop whereby the reinvestment assumptions are inconsistent and whereby misleading conclusions can be drawn if one uses the rate-of-return criterion. (For this example, the additional calculations will not be made as they are fairly tedious; however, a third example in section 2.7 will deal with this aspect.)

The ambiguities which sometimes confront the analyst using the rate-of-return method can be illustrated by comparing two projects of equal capital outlay but different service lives or terminal dates (Table 2.8). The rate-of-return method, as it is usually defined, would lead to the selection of project C while the net present value method would result in the selection of project B. To adopt the rate-of-return approach in preference to the net present value method (a policy we do not recommend) would be to assume that the reinvestment rate for the earnings of project C until the 30th year would be higher than 6 percent and would be large enough to increase the net present value from $47,895 to $54,082. (The reinvestment rate would have to be higher than 6 percent, or the cost of capital, if the net present value is to be increased.)

In this case, the inconsistency can be avoided in one of two ways. First, if the 6 percent cost of capital is deemed to be an appropriate figure for the entire 30-year period, it must be assumed that the reinvestment rate for funds released prior to the 30-year terminal date will also be 6 percent. Following, if the rate-of-return for project C is computed over the entire 30-year period, rather than the first 10 years, it would result in an overall 30-year rate-of-return of less than 6.5 percent. Thus the criteria of both the rate-of-return and net present value methods would indicate the preferability of project B.

Or, second, if it seemed reasonable to expect a reinvestment rate or set of dates different from the 6 percent cost of capital, the cost of capital figures to be used for discounting and computing the net present value should be changed accordingly and the net present value totals re-computed.

Of course, either procedure will result in the same project selection so long as the same assumptions are used with respect to reinvestment. However, since identical reinvestment assumptions are seldom (if ever) made by the analyst, engineers are strongly urged to adopt the net present value method in preference to the rate-of-return method.

2.7 CONCLUDING REMARKS

Several important issues pertaining to economic analysis methods have been discussed in this and the preceding chapter. By way of summarizing some of these principles, another example is included and discussed in detail.

Assume that two alternative projects will each require initial outlays of $100 (at year 0) and will each last two years (before renewal, replacement or abandonment);

TABLE 2.9

PROJECT ANALYSIS CALCULATIONS FOR PROJECTS X AND Y

Item	Project Alternatives	
	X	Y
Initial capital outlay (at year 0)	-$100.00	-$100.00
Annual earnings or benefits:		
Accruing at end of year 1	20.00	100.00
Accruing at end of year 2	120.00	31.25
Discounted rate-of-return for 2-yr period	20%	25%
Net present values for 2-yr period	$27.89	$23.58
Cost of capital	5%	5%

for convenience, assume that we have no information or analysis which permits knowledge of the circumstances following the end of the second year. The annual earnings during the first and second years of the two projects (which for convenience we will assume accrues at the end of the year in question) will be as given in Table 2.9. Also, the discounted rate-of-return and net present value figures for the two projects are included in the tabulation.[82]

For these calculations, the cost of capital (i.e., opportunity cost of capital) was assumed to be 5 percent over the 2-year period. Thus, other investment or reinvestment opportunities in the present and over the two-year period under analysis are assumed to provide earnings of 5 percent per annum.

Using the rate-of-return criterion, project Y would appear to be the best or most profitable but project X would be best if we used the net present value method. Why the ambiguity? And which is the better alternative? If the cost of capital is 5 percent, and if no other statements or assumptions are made with respect to the reinvestment rate for future earnings, alternative X is clearly superior. To understand this, let us determine the amount of capital we would have on hand at the end of the second year. At year 0, assume that we have $100 in a bank (or reserve fund) which we withdraw in order to invest in alternative X or Y; also, assume that our cost of capital is 5 percent (i.e., assume that other types of investments which are available to us will pay interest of 5 percent—no more, no less). Also, given no other information, we can only assume that in future years other investments will provide earnings of only 5 percent.

In this instance, for X, we will have a total of $141.00 on hand at the end of the second year (since the $20 earned at the end of year 1 was reinvested at 5 percent, thus providing $21 plus the $120 earned at the end of the second year). For Y, we will have a total of only $136.25 at the end of year 2 (since the $100 earned at the end of year 1 was reinvested at 5 percent, thus providing $105 plus the $31.25 earned at the end of year 2). Consequently, if we had adopted the rate-of-return criterion as our decision-making rule, we would have ended up at the end of year 2 with less capital than otherwise would have been possible. Or, to put the matter another way, to use the rate-of-return criterion and adopt Y over X would imply that the reinvestment earnings rate was higher than 5 percent (e.g., in this instance, the reinvestment rate would have had to be almost 11 percent for alternative Y to be more preferable). But in the absence of information other than the cost of capital, there is no reason to believe that the reinvestment rate is different from the cost of capital. Furthermore, if the reinvestment rate were different from the cost of capital, then necessarily the cost of capital must be changed (to be equal to the reinvestment rate) and thus the net present value figures should be changed accordingly.

As noted earlier, the rate-of-return as normally calculated implicitly assumes that the reinvestment rate (over the project life) is equal to the calculated rate-of-return. In essence, then, to adopt the rate-of-return criterion would be to assume that the reinvestment rate for project X would be 20 percent and that for project Y would be 25 percent. (It would appear illogical to anticipate different reinvestment earning rates

[82] This example was first brought to our attention by Professor Julius Margolis of Stanford University and later was found to be covered in the Bierman and Smidt text, The Capital Budgeting Decision.

for mutually exclusive projects; thus on these grounds alone, the rate-of-return criterion has shortcomings.) Given these reinvestment rates, the total accumulated earnings at the end of year 2 would be $144 for project X and $156.25 for project Y. Discounting these total earnings figures at the cost of capital (or 5 percent), and subtracting out the initial capital outlay, the net present value totals would be $30.61 for project X and $41.72 for project Y. In this case, since the same reinvestment assumptions have been made for both alternatives, both criteria would select project Y as best.

However, it would seem more appropriate to re-calculate the rate-of-return while assuming that the reinvestment rate for both projects was equal and that it was equal to the cost of capital; that is, a "corrected" rate-of-return should be calculated while assuming that the reinvestment rate for both projects was 5 percent. In this instance, it would be necessary to determine the discount rate for which the total accumulated earnings (after reinvestment) when discounted would just equal the discounted capital outlays. Earlier we computed the total accumulated earnings (at the end of 2 years) for a reinvestment rate of 5 percent; they were $141.00 for project X and $136.25 for project Y. For this case, the corrected rate-of-return would be 18.74 percent for project X and 16.73 percent for project Y; the net present value figures would be as given in Table 2.9. Again, since the same reinvestment assumption was made for both criteria, an unambiguous result would be forthcoming and project X would be selected as the best.

Again, and in conclusion, since the engineer seldom if ever makes the necessary additional calculations to insure that similar reinvestment rates are used, it would seem apparent that the simplest and most reliable manner to avoid ambiguous and often misleading decision-making conflicts would be to adopt the net present value method of economic analysis. The method is more straightforward than the rate-of-return method; reinvestment is handled in an explicit and simple fashion; and trial and error calculations are avoided. More importantly, an improper and ambiguous answer cannot occur.

CHAPTER THREE

Application of Economic Analysis Methods: A Practical Example

3.1 INTRODUCTION

The four principal analytical methods used for transport capital budgeting can be explained more definitively by considering some explicit examples. For this purpose, assume that three mutually exclusive, non-toll project alternatives are considered:[83]

1. y_0, continued operation of an existing 4-lane divided roadway without any improvement or expenditures other than those for periodic replacement, maintenance, and administration;
2. y_1, improvement and grade separation of the existing 4-lane roadway to eliminate grade crossings, rotaries, signals, etc.; and
3. y_2, construction of an additional 4-lane, fully controlled access, grade-separated roadway on entirely new rights-of-way and continued operation of existing roadway.

For simplicity, all initial capital expenditures for right-of-way will be assumed to have an indefinite life,[84] and all other (capital) construction items (pavement, bridges, etc.) will need replacement in 40 years. Also, it is assumed that these facilities have equal roadway lengths between common terminal points. While this particular example is relevant mainly to a reasonably dense, through traffic corridor, the principles would be much the same for other plausible examples as well.

3.2 STATEMENT OF BASIC ASSUMPTIONS AND INPUT DATA

3.2.1 Volume Data and User "Price"-Volume (or Supply) Functions

The resultant traffic volume for three projects is assumed to be as shown in Figure 3.1; for all three alternatives, it has been assumed that the annual volume will level off about 20 years from the present. While this latter assumption was made mainly for the sake of simplicity, it should be noted that in many cases it hardly is an unreasonable one.

Also, whereas most highway engineering economy studies usually assume that the volume using all alternatives will be the same (that is, that no additional volume will be induced by improvements), in this example a more realistic situation has been presumed to exist; that is, with each additional improvement more volume usage will occur. Further, the expected volume for project y_2 has been split between the new facility and the existing roadway.

These (expected) traffic volume curves, represent the interaction between supply and demand (while accounting for peak and off-peak variations), rather than any expression of demand apart from the circumstances of supply or capacity relationships.

---

[83] A fourth alternative—complete abandonment of the existing facility—is implied in all of these analyses. Obviously, for that case both the benefits and costs would be equal to zero.

[84] Or, to look at it another way, the right-of-way will always have a salvage value equal to its initial cost.

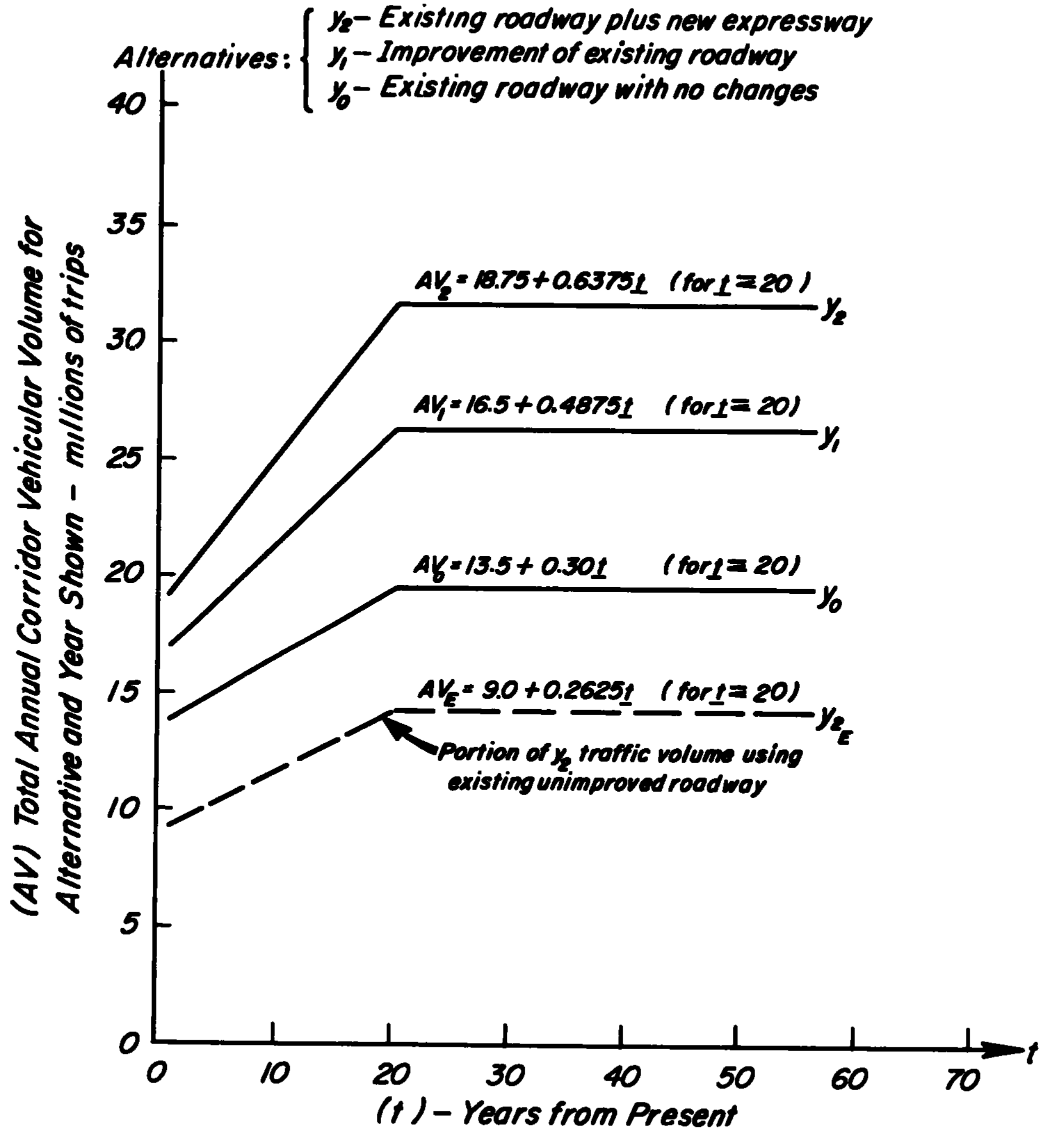

Figure 3.1. Annual traffic volumes by year and project.

In short, the curves or volume data in Figure 3.1 represent that demand for a facility, given its capacity, its performance, and the price for using it, as well as peaking characteristics.[85]

The expected annual traffic volume patterns will be expressed as follows:

1. Project y_0:

$$AV_0 = 13.5 + 0.30t \quad (3.1)$$

[85]Importantly, we have assumed continuance of the usual highway user tax pricing and we have assumed a uniform price or tax structure.

2. Project y_1:

$$AV_1 = 16.5 + 0.4875t \tag{3.2}$$

3. Project y_2:

$$AV_2 = 18.75 + 0.6375t \tag{3.3}$$

For these expressions, AV_y is the annual corridor traffic volume (in millions of trips) for the y th project and t is the number of years from year zero (but no more than 20). Also, for project y_2,

$$AV_{E_2} = 9.0 + 0.2625t \tag{3.4}$$

where AV_{E_2} is the portion of the total project y_2 corridor volume that is using the existing roadway; thus AV_2 minus AV_{E_2} will use the new facility.

In these analyses, it will be assumed that traffic flow (and thus travel costs and benefits) will be affected only between common sets of points along the facilities being compared and analyzed. Thus, we will analyze only the effects on the existing, improved, or new facility, and will ignore any second-order travel costs or benefits occurring on other facilities that may be affected by the conditions on the facilities in question. Furthermore, the traffic volume data (Fig. 3.1) can be viewed as resulting from the intersection of supply (price-volume) and peak and off-peak demand curves.

In other words, it is implied that the volume data in Figure 3.1 were determined from intersections of demand functions (plotted by year) and supply (or price-volume) relationships; this can be illustrated by Figure 3.2. The supply or price-volume curves for y_0 (the existing unimproved roadway) and for y_1 (the existing roadway improved by grade separation) are shown along with the peak- and off-peak period demand functions for the first and twentieth years hence. (The demand functions have been stratified by peak and off-peak periods to reflect important differences during certain hours of the day and the peaking and congestion that result therefrom.) The price-volume curve for the new facility (y_N) is included merely for illustrative purposes and cannot be related to the demand curves shown since the demand for project y_2 must be split between the new facility (or y_N) and the existing roadway (or y_E).

The price-volume or supply functions which were used in determining the trip price to users (per mile of journey) were varied according to the facility capacity and design; these expressions were chosen so as to include all costs, whether money or non-money, which were perceived by users in their tripmaking. Further, for convenience it was assumed that users in making their trip choices and in deciding whether or not to make a trip accounted for total vehicle ownership and operating costs, as well as congestion, time, and discomfort costs;[86] these user price-volume (or supply) functions were assumed to be of the following form:

1. Existing unimproved roadway (in cents per trip mile):

$$p_{y_0} = p_{y_E} = 7.0 + \frac{350}{31-0.013q_x} \tag{3.5}$$

[86]We do not argue the "typicality" or reasonableness of this assumption, but make it strictly for convenience.

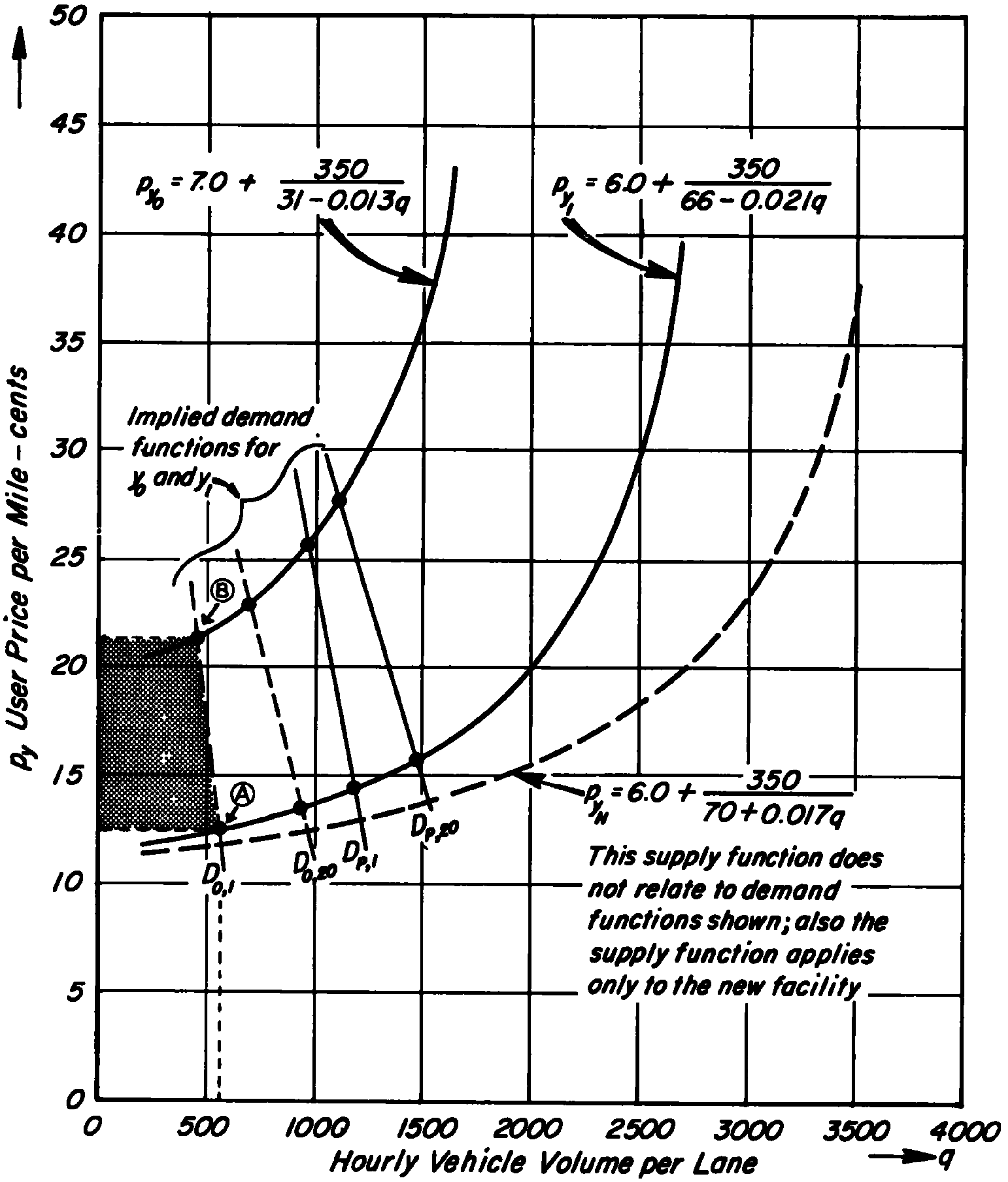

Figure 3.2. User price-volume relationships by project.

where

q_x = hourly volume per lane during x th hour or demand period (but less than 2380), and

p_{y_0} = p_{y_E} = total price (or cost to users) of trip on existing roadway per mile (including all taxes).

2. Improved existing roadway (in cents per trip mile):

$$p_{y_1} = 6.0 + \frac{350}{66-0.021q_x} \qquad (3.6)$$

where

p_{y_1} = total price (or cost to users) of trip on improved roadway per mile (including all taxes).

3. New facility (in cents per trip mile):

$$p_{y_N} = 6.0 + \frac{350}{70-0.017q_x} \quad (3.7)$$

where

p_{y_N} = total price (or cost to users) of trip on new facility per mile (including all taxes).

These user price functions are intended to include and account for all changes in operating and maintenance costs that occur with changes in congestion and speed as either volume levels or facility capacities change.

More generally, these price-volume relationships can be viewed as:

$$p = b + \frac{f}{v} = b + \frac{ft}{60} \quad (3.8)$$

or

$$p = b + \frac{f}{v_0 - aq} \quad (3.9)$$

where p is the average travel price per mile for a composite vehicle[87] to move over a distance of one mile while traveling at a speed v (in miles per hour) and at a flow or volume rate q (in hourly vehicles per lane); a, b, and f are parameters whose values depend on the facility design, capacity, and operation and on the vehicle type and performance characteristics; y_0 is the average travel speed on a given facility under very light flow or volume conditions, and t is the travel time (in minutes) to move one mile.

By using a speed-distance-time relationship, the user price, p, can be stated as a function of b, f, and t, where t is the travel time for an average vehicle to move over a distance of one mile at a flow q and at speed v. Then, by taking the derivative of p with respect to t, the increment in unit user price per minute of travel time and congestion will be found to be equal to f divided by 60; this incremental unit cost applies, of course, to the vehicle's occupants as a group and is not the additional cost per minute per person. In short, these particular price-volume relationships imply that the occupants of the average vehicle pay about 5.8 cents for each additional minute of travel time, congestion, discomfort, and inconvenience; and if the average vehicle has, say, almost two occupants (probably not unreasonable for the corridor situation assumed here), the additional price of each minute of time, congestion, discomfort, and inconvenience to each passenger is about 3 cents.[88]

The incremental unit time and congestion price is noted merely to indicate what our formulation implies rather than to attest to its validity (which is not the subject of our attention for this example).

A crucial aspect to the analysis is the determination of hourly volume per lane (q_x) that is traveling in the x th hour or demand period. This determination requires certain assumptions about peaking variations, all of which complicate the analysis (though

[87] Heavy and light vehicles have been placed on a composite basis by use of factors indicating the truck requirements relative to those of light vehicles.

[88] Please note that we refer to the price of time and congestion (i.e., discomfort and inconvenience, etc.) rather than narrowly to the price of time. Also, by saying that there is a user price per minute of time and congestion which amounts to 3 cents per passenger implies that travelers would in fact pay that amount in monetary terms to avoid the time and discomfort involved (while still making the trip, of course). Also, and as indicated in Eqs. 3.5, 3.6, and 3.7, these unit price figures assume that f is equal to 350.

TABLE 3.1

PEAK-PERIOD TRAVEL AS A PERCENTAGE OF TOTAL DAILY VOLUME

Highway Facility or Area	Percentage of Total Daily Volume Traveling During 4 Peak Hours (1960-1962)
Chicago Area	32
Detroit Ford-Lodge Expressway	28
Chicago Congress St. Expressway	30
Washington Memorial Bridge	44
Boston Route 128	29

are entirely necessary if we are to properly account for peak and off-peak hour differences in travel speed and congestion). First, it is assumed that all hourly volumes during the peak period will be equal and that all hourly volumes during the off-peak period will be equal; thus, it is only necessary to determine q_p, the average hourly volume per lane during the peak period, and q_0, the average hourly volume per lane during the off-peak period.[89]

In addition, it is assumed that peak periods will occur for only 4 hours on each weekday (of which there are roughly 255), thus calling for a total of 1,020 hours of peak period traffic during the year. The remaining hours of traffic are regarded as the total amount of off-peak traffic. It was also assumed that the hourly volume during an average peak-period hour would be 10 percent of the average annual daily traffic during year 0 and would decrease to 6.667 percent of AADT during the twentieth year (that is, the percentage would decrease by ⅙ percent per year from the initial 10 percent). In other words, the percentage of the total annual volume occurring during the daily 4-hour peak-period would range from 40 percent in the beginning down to slightly over 26 percent in the twentieth year.

Obviously, within the 4-hour peak-period (say, 2 hours in the morning and 2 in the afternoon) the volumes as a percentage of AADT could range between the usual 10 to 15 percent so familiar to traffic and highway engineers, though this variation is hidden by our averaging process. In gross, however, the percentages falling within the peak-period (that is, 4 peak hours during the day), ranging from 40 down to 26 percent over a 20-year period, appear reasonable; a rough check is privided by Table 3.1.

Shown in equation form, the hourly volumes per lane during the peak and off-peak periods (of the t th year after year 0) are as follows:

$$q_p = \left(\frac{AV}{365}\right)(25,000 - 416.5t) \tag{3.10}$$

[89]Because of the extremely low volumes which are typically experienced during late p.m. and early a.m. hours, weekdays have been assumed to have only 18 hours of traffic flow so that we will have off-peak period traffic during 14 hours of the day and the peak-period volume during 4 hours of the day (i.e., we have assumed that 6 hours of the average day will have 0 volume, and thus that the average hourly off-peak period volume will be higher than in actuality); however, because of the flatness of the price-volume curves in the low volume region and the relatively high volumes during daytime off-peak hours, this assumption will tend to provide more realistic overall results than would be possible if we used a 24-hour period for computing volumes (i.e., without it, the average off-peak hourly volume would have reduced the user prices below their proper level and resulted in their understatement, at least in gross).

$$q_0 = \frac{AV - 0.00408q_P}{0.0222} \qquad (3.11)$$

where q_P is the hourly volume per lane during the peak-period, q_0 is the hourly volume per lane during the off-peak period, t is the number of years from year 0 (or the present), and AV is the annual traffic volume during the t th year after year 0 (in millions). Also, it should be recalled that these functions are based on conditions for 4-lane facilities of the character noted earlier.

One final assumption had to be made regarding the traffic volumes; this pertained to the split of the corridor volumes between the existing and new facilities for project y_2 when a new facility was added to the roadway already in existence. This was accomplished on an arbitrary basis, with 48 percent of the total corridor traffic assumed to be using the existing facility in year 0 and decreasing to only 44.25 percent in the twentieth year (and remaining at that level thereafter).

All in all, these assumptions appear to be internally consistent and to provide a realistic basis for explaining and demonstrating an adequate economic analysis example.

3.2.2 Facility Costs

The next item of input data of importance regards facility costs, both for initial capital outlays and continuing expenses. These data, it must be emphasized, were not chosen for their typicality but rather as example figures merely to be used in this illustrative economic analysis. (Admittedly, though, we attempted to select a range of cost data which would place us in the "ball park" for relatively high density, intercity corridor highways in the United States.)

Rather than limit our attention to projects having only one set of initial capital outlays, we choose to carry out the complete analysis for two sets of initial capital outlays, one for so-called high cost systems and the other for so-called low cost systems. The purpose of varying this parameter was simply to illustrate the shift in project choice which can result from projects of varying capital investment at different interest rates.

The initial capital outlays and annual maintenance and administration expenditures for the different facilities and projects, and for both high and low cost conditions are given in Table 3.2.

3.2.3 User Tax Payments

Finally, it was necessary to estimate the level and amount of user tax contributions attributable to travel on the various types of facilities being analyzed. A three-step process was used for this purpose. First, it was necessary to compute the user contributions which are presently being made at local, state, and federal levels, in total. Second, it was necessary to separate these user taxes into that portion that is fixed or invariant with speed changes and that which is variable with speed or gasoline consumption. Third, it was necessary to estimate the expected average vehicular speeds and gasoline consumption rates which travelers will experience on the particular facilities and projects being analyzed.

User tax contributions (local, state, and federal, in total) in the United States for calendar year 1962 were used as the basis of these illustrative calculations and were as given in Table 3.3 along with the appropriate vehicle-miles of travel and gallons of gasoline consumed. (All federal, state, and local excises were excluded.) If we separate this tax into the component which varies with respect to speed and gasoline consumption and that which is fixed, these taxes can be restated as follows:

1. Fixed component of user tax (in cents per vehicle-mile):

$$UFM = 0.2859 \qquad (3.12)$$

where UFM is the fixed component of user tax per vehicle-mile; basically, it includes the registration fees, motor vehicle use and lubricating oil taxes.

TABLE 3.2

INITIAL CAPITAL OUTLAYS AND CONTINUING COSTS FOR PROJECTS AND FACILITIES*

Project	Facility	Initial Capital Outlays**		Annual Maintenance and Operating Costs
		Construction	Right-of-Way	
		(a) Low Cost Systems		
y_0	Existing road unimproved	None	None	$44,700
y_1	Existing road improved	$600,000	None	$31,600
y_2	Existing road unimproved	None	None	$27,300
	New facility	$876,000	$394,000	36,200
	y_2 total	$876,000	$394,000	$63,500
		(b) High Cost Systems		
y_0	Existing road unimproved	None	None	$44,700
y_1	Existing road improved	$1,100,000	$354,000	$31,600
y_2	Existing road unimproved	None	None	$27,300
	New facility	$2,752,000	$788,000	36,200
	y_2 total	$2,752,000	$788,000	$63,500

*Per mile of roadway.
**Initial capital outlays are assumed to take place at year 0; it will be assumed that right-of-way has indefinite life (and is entirely salvageable at any date) and that construction items must be replaced at 40 years.

TABLE 3.3

MOTOR VEHICLE USER TAXES (1962)*

User Tax Items:	Total Vehicle User Tax:
State registration tax	$2.060 billion
State gasoline tax	3.762
Federal motor fuel tax	2.356
Federal lub. oil tax	0.046
Federal motor vehicle use tax	0.089
Total**	$8.313 billion
Vehicle-miles of travel†	767.774 billion
Gasoline consumed by motor vehicles††	61.696 billion

*Automobile Facts and Figures, 1964 Ed., Automobile Manufacturers Association, p. 50 and 58.
**Excludes about $2.491 billions in Federal excises on vehicles and automotive products, as well as other city, county, and state fees.
†Op. cit., p. 46.
††Ibid., p. 59.

2. Variable component of user tax (in cents per gallon of gas):

$$UVM = 9.915 \qquad (3.13)$$

where UVM is the variable component of user tax per gallon and is based on the gasoline consumed and thus on speed of travel; it includes the federal motor fuel taxes and the state gasoline taxes.

The application of these user tax components requires determination of the gasoline consumption requirements for the various facilities in question; since gasoline consumption is a function of travel speed, it first is necessary to determine the expected travel speeds on the facilities. As pointed out earlier, or at least as can be surmised from Eq. 3.9, the speeds on the various facilities vary with the facility design and capacity and with the volume using the facility; expressed functionally,

$$v = v_0 - aq \qquad (3.14)$$

where v (in miles per hour) is the travel speed of an average vehicle in a flow of volume q (in vehicles per hour per lane), v_0 is the average travel speed on a given facility under very light flow or volume conditions, and a is a parameter whose value depends on the facility design, capacity, and operation. Consequently, by determining the volumes during peak and off-peak hours (or, q_0 and q_p) and substituting these volumes of q values into Eq. 3.14, the appropriate expected average speeds on the various facilities can be determined for each year over the 40-year period of analysis.[90]

All the above calculations were carried out for each of the facilities and projects and are included in the appendix to Chapter 3. Appendix 3.1 includes the yearly annual volumes on each facility for each project as determined from Eqs. 3.1 through 3.4. These data (Appendix 3.1) were used, in turn, to determine the average hourly peak-period volume (q_p) and the average hourly off-peak period volume (q_0) on the various facilities; these volumes were determined by year (Appendix 3.2). Then, using Eq. 3.14 together with the hourly volume data in Appendix 3.2, the average speeds of travel during the peak and off-peak hours on the various facilities were computed; the results are shown in Appendix 3.3

Finally, the speeds as computed above (Appendix 3.3) were applied to gasoline consumption-speed relationships similar to those illustrated in the AASHO Red Book or in Oglesby and Hewes textbook. However, since the difference between the peak and off-peak speeds for each facility was reasonably small (at least when related to the somewhat indefinite gasoline consumption-speed relationships) and since the speeds for each facility did not increase substantially over the 20-year period of annual volume increases, we chose to calculate one weighted average speed for each facility (to cover both peak and off-peak speeds, and the trend over the 20-year period) and to apply this single figure to the gasoline consumption relationships; the figures chosen are given in Table 3.4(a) in addition to the corresponding gasoline consumption rate.

The gasoline consumption rates for the facilities can now be applied to the variable component of the user tax as given in Eq. 3.13; the resultant user tax per vehicle-mile, to include both fixed and variable components, is summarized in Table 3.4(b). These unit user taxes when applied to the annual volume data in Appendix 3.1 will, of course, provide estimates of the annual user tax payments which are made for travel on the various facilities.

3.2.4 Summary of Costs and Benefits To Be Included in Analysis

At this point, it will be useful to recapitulate some aspects regarding measurement and inclusion of user travel costs and benefits. First, to look at the benefit side of the analysis, in these analyses user travel benefits or value will be included only to

---

[90] The values for the parameter a and for v_0 are shown in Eqs. 3.5 through 3.7 for the different facilities.

TABLE 3.4

(a) WEIGHTED AVERAGE SPEEDS AND GASOLINE CONSUMPTION RATES

Project	Facility	Weighted Average Speed (mph)	Gas Consumption (gal/veh-mi)
y_0	Existing unimproved	21.3	0.057
y_1	Existing improved	45.0	0.068
y_2	Existing unimproved, y_{2_E}	23.9	0.056
	New facility, y_{2_N}	58.8	0.105

(b) USER TAX PAYMENTS PER VEHICLE-MILE

Project	Facility	User Taxes per Vehicle-Mile (¢/veh-mi)		
		Variable Component	Fixed Component	Total User Tax
y_0	Existing unimproved	0.565	0.286	0.851
y_1	Existing improved	0.674	0.286	0.960
y_2	Existing unimproved, y_{2_E}	0.555	0.286	0.841
	New facility, y_{2_N}	1.041	0.286	1.327

the extent of actual money and non-money payments which users actually make or think they make (whether perceived in the tripmaking choice or not)[91]; thus consumer surplus (that is, value received by the traveler over and above his payment) will be excluded. Also, it is assumed that the user tripmaking price (that is, the cost to the user and thus his price paid or perceived) as calculated by Eqs. 3.5 through 3.7 will constitute the entirety of the user price and payments (both money and non-money). Consequently, use of Eqs. 3.5 through 3.7, together with the peak and off-peak hourly volume data in Appendix 3.2, will provide estimates of the user travel benefits, by year;[92] these benefit data are included in Appendix 3.4, first broken down by peak and off-peak period travel for each facility and then combined to provide total annual travel benefits for each project, by year. Finally, since external non-travel benefits were excluded from these analyses, and since we shall assume that there are no non-user revenues, these figures represent the total allowable benefit to be considered in the economic analyses.

Second, to look at the cost side of the analysis, there are only three types of costs which we shall include: (a) facility construction and land acquisition costs; (b) facility

[91] In other words, we are assuming for example that the user price equations include all vehicle ownership and operating costs which are actually paid by travelers (at one time or another and in one way or another), and we are assuming that he therefore explicitly accounts for them in his tripmaking decision-making calculus. We do not argue necessarily that this is a good assumption, but make it merely for convenience.

[92] Actually these estimates have to be computed in a two-step process. First, by using the hourly volume data in Appendix 3.2 and Eqs. 3.5 through 3.7, we can obtain estimates of the tripmaking price to each user or vehicle (that is, price per vehicle trip); these unit user prices are shown in Appendix 3.5. Second, these unit prices (or price per vehicle trip) must be multiplied first by the volume data in Appendix 3.2, and then the peak hour prices must be multiplied by the number of yearly peak-period hours (or 1,020) and the off-peak hour prices must be multiplied by the number of yearly off-peak period hours (or 5,550).

operating, maintenance, and administration costs; and (c) user travel costs. (Thus certain social dislocation costs have been excluded from our attention, again for convenience.) The first two cost items are straightforward and treated as outlined in Table 3.2. The third item, or user travel costs, deserves particular attention in one respect. That is, user taxes must be excluded from those costs which are experienced by and paid for (in money or non-money terms)[93] by travelers or users. In short, for these analyses, the user travel costs which will be included as part of the system costs will be measured simply by taking the difference between the user travel benefits less the user taxes that are paid in the course of travel on the particular facility;[94] thus the appropriate user travel costs to be included herein can be determined simply by deducting the appropriate user taxes from the total user benefits recorded in Appendix 3.4(b). (As outlined earlier, the total user taxes can be determined by multiplying the unit user taxes in Table 3.4(b) times the annual volumes in Appendix 3.1 and summing over the 40-year analysis period.)

An alternative view of this procedure is to say that the highway engineer must determine the relationship between the demand for his highways and the cost of providing these facilities in order to assess the desirability of such investments. In this regard, his role is much the same as that of any entrepreneur in the private economy who must decide whether it is economically worthwhile to produce; i.e., to introduce a product, whether it is a machine to be used by other businessmen or a household durable to be sold directly to consumers. Indeed, it was a desire for rough parity between private and public investment decisions that mainly underlaid the exclusion of consumer surplus from the highway benefit calculations. In essence, the above procedures boil down to asserting that the highway engineer, like the private entrepreneur, must base his decisions whether to build or not on an estimate of the price at which the services produced might be sold, that is the market cleared. The calculation of user cost savings recommended here is really an indirect method of attempting to estimate the demand curve for the transport services under analysis and thus the prices at which these services might be sold. In the above analysis, moreover, an extremely conservative estimate of possible "sales revenues" for the highway has been used: namely, those revenues associated with the price and volume on the demand curve at the point relating to the existing structure of user taxes. It seems entirely possible, indeed probable, that for really superior facilities in the circumstances outlined, a considerable number of consumers might be willing to pay far more than this "user tax price"; therefore, considerably more revenue might be obtained from the facility if needed to justify or cover costs.

The level of user tax collections may be a particularly misleading and conservative estimate of potential benefits in cases where these taxes are exceptionally high or low. This will be especially true if a tradition of low user taxes has developed. Even if the opposite occurs (i.e., user taxes are very high), the benefit estimate may still be conservative because if the user tax is high enough it may inhibit traffic development and use. In economists' jargon one policy (too low taxes) places one below the unit elastic (maximum revenue) point on the demand curve and the other policy above it. In short, the central question is always the same: does the demand curve as defined by consumer's willingness to pay for the transport facility provide sufficient scope for some legitimate and accepted pricing policy to produce sufficient revenues to pay for the facility?

3.3 ANALYSES TO BE CONDUCTED

Four principal analytical techniques or procedures commonly applied to transport costs and benefits are (a) net present value method, (b) discounted rate-of-return

---

[93]So long as the traveler will be willing to pay equivalent monetary amounts to avoid the non-money consequences.

[94]This assumption is tantamount to saying that user payments for parking just equal the costs for providing those facilities (interest included) and that user insurance premium payments just equal the total accident costs for society, etc. Again, this assumption is made in order to simplify the analyses.

method, (c) annual cost method (using equivalent annual costs), and (d) benefit-cost ratio method (using equivalent annual costs and benefits). This order of the analyses minimizes the calculations; in short, if net present value figures are available, the necessity of computing the rate-of-return on incremental system costs is obviated (a major saving in computations in most cases and certainly in this one).

In order to apply all but the rate-of-return method it is necessary to stipulate an interest or discount rate (in economic jargon, the cost of capital). For this purpose, and in order to explore the implications of varying the interest rate, we shall vary the discount rate, selecting 4, 6, and 8 percent for analysis.

An explicit interest rate is not necessary in order to compute the rate-of-return, but it is necessary nevertheless to state explicitly the appropriate cost of capital—sometimes called the minimum attractive rate-of-return; oftentimes this rate is called the "cutoff rate," or rate of interest at which additional investment or cost commitment is cut off or stopped should the calculated rate-of-return not be at least as high. Consequently, and contrary to the arguments of some proponents of the rate-of-return method, it is necessary to state explicitly the cost of capital if proper decisions are to be made.

Again, the project alternatives shall be analyzed on the basis of a terminal date or analysis period of 40 years.

3.3.1 Net Present Value (or Net Present Worth) Calculations

Computationally, this procedure is by far the simplest of the methods when the costs or benefits vary other than linearly over the analysis period. Since in these examples, the user tripmaking benefits vary non-linearly from year to year because of the non-linear changes in speed and congestion conditions (and thus user travel costs and benefits also vary accordingly), net present value is by far the most desirable method of analysis, even aside from the fact that it virtually always gives the proper decision-making result.[95]

Essentially, the net present value method calls for reducing all future and present costs or benefits to the same basis, and normally to present-day or year 0 values. This is accomplished in the simplest sense by applying the discount factor (or so-called single payment present value factor) to the cost or benefit occurring in year t, as follows:

$$\text{Discount factor} = pwf'_{i,t} = \frac{1}{(1+i)^t} \qquad (3.15)$$

and

$$\text{Discounted cost or benefit} = (pwf'_{i,t})\,(\text{cost or benefit in year } t)$$

$$= \frac{\text{cost (or benefit) item in year } t}{(1+i)^t}$$

In the case where cost or benefit items over the years vary and are not uniform, such as with user travel benefits and user travel costs, the cost or benefit item for each year must be discounted separately and the total accumulated. The discount factor in Eq. 3.15 was separately applied to the annual travel benefits of each year for each facility (Appendix 3.4); the resultant discounted benefits (or, present value of user

---

[95] As we shall see, with any other method which deals with costs or benefits that vary other than linearly over the analysis period, it will be necessary to first reduce the costs or benefits to a present value basis and then to transform them into a rate-of-return or benefit-cost ratio or into equivalent annual costs or benefits. Thus, one computational step is always saved.

benefits) are tabulated by year in Appendix 3.6 for each discount rate and for each facility, along with the cumulative user benefits over the 40-year period.[96]

Since the travel volumes and annual user benefits for each facility remained constant for the twenty-first through fortieth years (and were equal to that occurring in the twentieth year), the discounted benefits or present value of benefits for those 20 years in total can be computed more simply by using a so-called "uniform series present value factor." This factor, or $pwf_{i,t}$, quite simply is equal to the sum of the series of single-payment present value factors for years 1 through t, each factor of which in turn is to be multiplied by the same annual user benefits; it is

$$pwf_{i,t} = pwf'_{i,1} + pwf'_{i,2} + \dots + pwf'_{i,t}$$

$$= \frac{1}{(1+i)} + \frac{1}{(1+i)^2} + \dots + \frac{1}{(1+i)^t}$$

This summation is a geometric progression, and reduces to

$$pwf_{i,t} = \sum_{x=1}^{t} \frac{(1+i)^x - 1}{i(1+i)^x} \qquad (3.16)$$

Further, it can be shown that the uniform series factor applying to a uniform or constant annual series of end-of-year payments starting with year n + 1 and continuing through year t is:

$$pwf_{i,t-n} = pwf_{i,t} - pwf_{i,n} \qquad (3.17)$$

Multiplying the annual benefits time the appropriate uniform series present value factor (or difference between factors) will provide the sum of the discounted benefits over the appropriate period and not the annual discounted benefits. For example, if we multiply the annual benefits for years 21 through 40 for project y_0 (which were $4650 thousands a year) times the difference between the appropriate uniform series present value factors for a 4 percent interest rate (which is 19.793 minus 13.590), we arrive at a figure of $28,844 thousands, which is the total discounted user benefits for years 21 through 40 for project y_0 at a 4 percent interest rate.[97]

The annual highway maintenance and administration costs were assumed to be constant over the 40-year period, and thus their discounted values can easily be determined by use of the uniform series present value factors; the discounted values for the annual maintenance and administration costs are tabulated in Appendix 3.7, in total and broken down for the first 20 and the last 20 years of the 40-year analysis period. Looking just at the total figure, the total 40-year discounted highway maintenance and administration costs for project y_1 at a 4 percent interest rate were computed by multiplying the annual cost (from Table 3.2) of $31,600 times the uniform series present value factor[98] of 19.793, resulting in total 40-year discounted costs of $624,000.

---

[96]The discounted benefits for the tenth year with project y_0, for example, were as follows for a 4 percent interest rate: Discounted benefits $= \left(\frac{1}{1+0.04}\right)^{10}$ ($3,787,000) = (0.6756) ($3,787,000) = $2,558,000.

[97]Both single-payment and uniform series present value factor figures can be found tabulated in many economic texts, or mathematical handbooks; Grant and Ireson's tables are particularly useful.

[98]The $pwf_{4,40} = \frac{(1+0.04)^{40} - 1}{0.04\,(1+0.04)^{40}} = 19.793$, from Eq. 3.16.

The initial capital outlays for construction and right-of-way were incurred at year 0, according to our assumptions, and thus are already in present value form. However, the salvage value of the right-of-way in year 40 must be discounted to its present value in year 0 by applying a single-payment present value factor. Thus, using a discount rate of 4 percent, the present value of the right-of-way salvage value of high-cost project y_1 is found to be $74,000 by multiplying the single-payment factor[99] of 0.2083 times the initial right-of-way capital outlay of $354,000 (from Table 3.2). Thus, the net present value of right-of-way costs is equal to the initial outlays of $354,000 less the $74,000 salvage value for a net figure of $280,000. The present values for construction, right-of-way, and net right-of-way costs are provided in Appendix 3.8, by project, by high or low cost systems, and by interest rates.

The final cost item to be calculated is that of user costs, which as defined earlier are equal to user travel benefits less user taxes (for the case in which consumer surplus is excluded). Since the discounted user travel benefits are given in Appendix 3.6, the discounted user costs can be computed by subtracting out the discounted user taxes. From the earlier description and the tabulation of unit user taxes in Table 3.4(b), it is apparent that user taxes are proportional to tripmaking volume (per mile) and thus can be determined simply by multiplying the annual facility volumes of Appendix 3.1 times the unit user taxes of Table 3.4(b). Diagrammetrically, this product of user volume and unit taxes, by year, would be as shown in Figure 3.3; briefly, the annual taxes would increase from an initial annual tax total of AT_1 in year 1 to AT_{10} in year 10, and would then remain at that constant level thereafter, at least for this example. To place this t-year stream of annual user taxes on either a present value or equivalent annual basis requires: (a) either discounting the annual taxes for each year separately, year by year, and then summing these amounts; or (b) discounting the uniform increments in annual taxes (from year 1 to year 10 in this case), and discounting the initial annual tax over t years, and, finally, discounting the extra annual taxes over the initial level once they reach a constant annual tax level (at year 10) over the t - 10 years.

The first of these two ways of discounting is the simplest conceptually, but the most tedious computationally. Analytically, the total discounted user taxes over t years or (TAT), would be:

$$TAT = \frac{AT_1}{(1+i)} + \frac{AT_2}{(1+i)^2} + \frac{AT_3}{(1+i)^3} + \dots + \frac{AT_t}{(1+i)^t} \tag{3.18}$$

which could be restated as:

$$TAT = \frac{AT_1}{(1+i)} + \frac{(AT_1+g)}{(1+i)^2} + \frac{(AT_1+2g)}{(1+i)^3} + \dots + \frac{\left[AT_1+(n-1)g\right]}{(1+i)^n} + \frac{\left[AT_1+(n-1)g\right]}{(1+i)^{n+1}} + \dots + \frac{\left[AT_1+(n-1)g\right]}{(1+i)^t} \tag{3.19}$$

where g is the uniform annual increase in annual user tax which continues through the nth year, AT_t is the annual user tax in year t, and AT_1 is the initial annual user tax or that in year 1; also, i is the discount or interest rate.

For the second method, Eq. 3.19 would be restated as follows (see Fig. 3.3):

$$TAT = AT_1 \sum_{x=1}^{n} \frac{1}{(1+i)^x} + g \sum_{x=1}^{n} \frac{x-1}{(1+i)^x} + \left[AT_1+(n-1)g\right] \sum_{x=n+1}^{t} \frac{1}{(1+i)^x} \tag{3.20}$$

[99] From Eq. 3.15, $pwf'_{4,40} = \frac{1}{(1+0.04)^{40}} = 0.2083.$

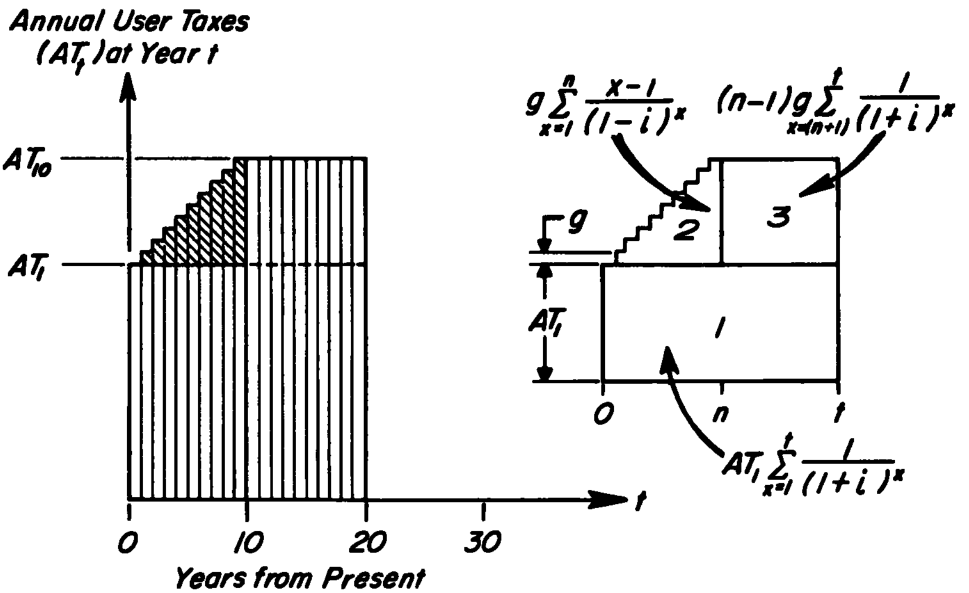

Figure 3.3. Annual user tax flow by year (it is assumed that the user taxes accrue at end of year t).

$$TAT = AT_1 \sum_{x=1}^{t} \frac{1}{(1+i)^x} + g \sum_{x=1}^{n} \frac{x-1}{(1+i)^x} + (n-1)g \sum_{x=n+1}^{t} \frac{1}{(1+i)^x} \qquad (3.21)$$

Eq. 3.21 calls for separating the discounting of user taxes into three distinct parts as indicated in the equation and in Figure 3.3. The summation for the first and last terms or parts of Eq. 3.21 corresponds to the uniform series present value factors which were outlined earlier in Eqs. 3.16 and 3.17, and thus can be represented by $(pwf_{i,t})$ and $(pwf_{i,t} - pwf_{i,n})$, respectively. An appropriate expression for the summation for the middle or second term of Eq. 3.21 can be shown to be as follows:

$$gpwf_{i,n} = \sum_{x=1}^{n} \frac{x-1}{(1+i)^x} = \left[\frac{(1+i)^n - 1}{i^2(1+i)^n} - \frac{n}{i(1+i)^n} \right] \qquad (3.22)$$

Values for Eq. 3.22, or so-called gradient present value factors, can be found tabulated in certain economic or math texts (such as Appendix Table E-24 in Grant and Ireson).

Including all the above "shorthand" notation, Eq. 3.21 becomes

$$TAT = AT_1 (pwf_{i,t}) + (g)(gpwf_{i,n}) + (n-1)(g)(pwf_{i,t} - pwf_{i,n}) \qquad (3.23)$$

Applying these equations and factors to the data for project y_0, for example, from Eq. 3.1 we can determine both the initial traffic volume and gradient or annual increase (the former of which is 13.8 million trips in year 1, and which increases 0.30 million trips a year up through the twentieth year and then remains constant thereafter). Corresponding to the symbols of Eqs. 3.19 through 3.23, the value of AT_1 is $117,452 (or 13.8 million times the unit user tax of 0.851 cents per vehicle-mile); the value of g, the gradient or annual increase in tax, is $2553; n is 20 years, and t is 40 years. For an interest rate of 4 percent, the value for the first term of Eq. 3.23 becomes $2,325,000 (or $117,452 times 19.793), that for the second term becomes $285,000 (or $2553 times 111.56), and for the third term becomes $301,000 (or 19 times $2553 times the difference of 19.793 and 13.590); the total discounted user taxes or present value of the total user taxes is about $2,910,000 for project y_0 at a 4 percent interest rate. This figure compares with that included in Appendix 3.9, which gives the discounted user taxes for all projects and interest rates.

These discounted user taxes when deducted from the discounted user tripmaking benefit totals (Appendix 3.6) will provide estimates of the user travel costs for each project and interest rate; these user travel cost figures are shown in part I of Appendix 3.10, in present value terms, of course.

All of the enumerated data are necessary to the computation of the net present value for each project and interest rate; they have been combined for that purpose in Appendix 3.10, and the project of highest net present value for each interest rate condition has been circled. These net present value data are also illustrated in Figures 3.4 and 3.5, the first of these pertaining to low-cost conditions and the second to high-cost conditions.

Using the criterion of maximum net present value in order to accept or reject projects (economically) and to select the best project (of those which are not rejected) would result in choices being made for the various systems being analyzed as shown in Table 3.5.

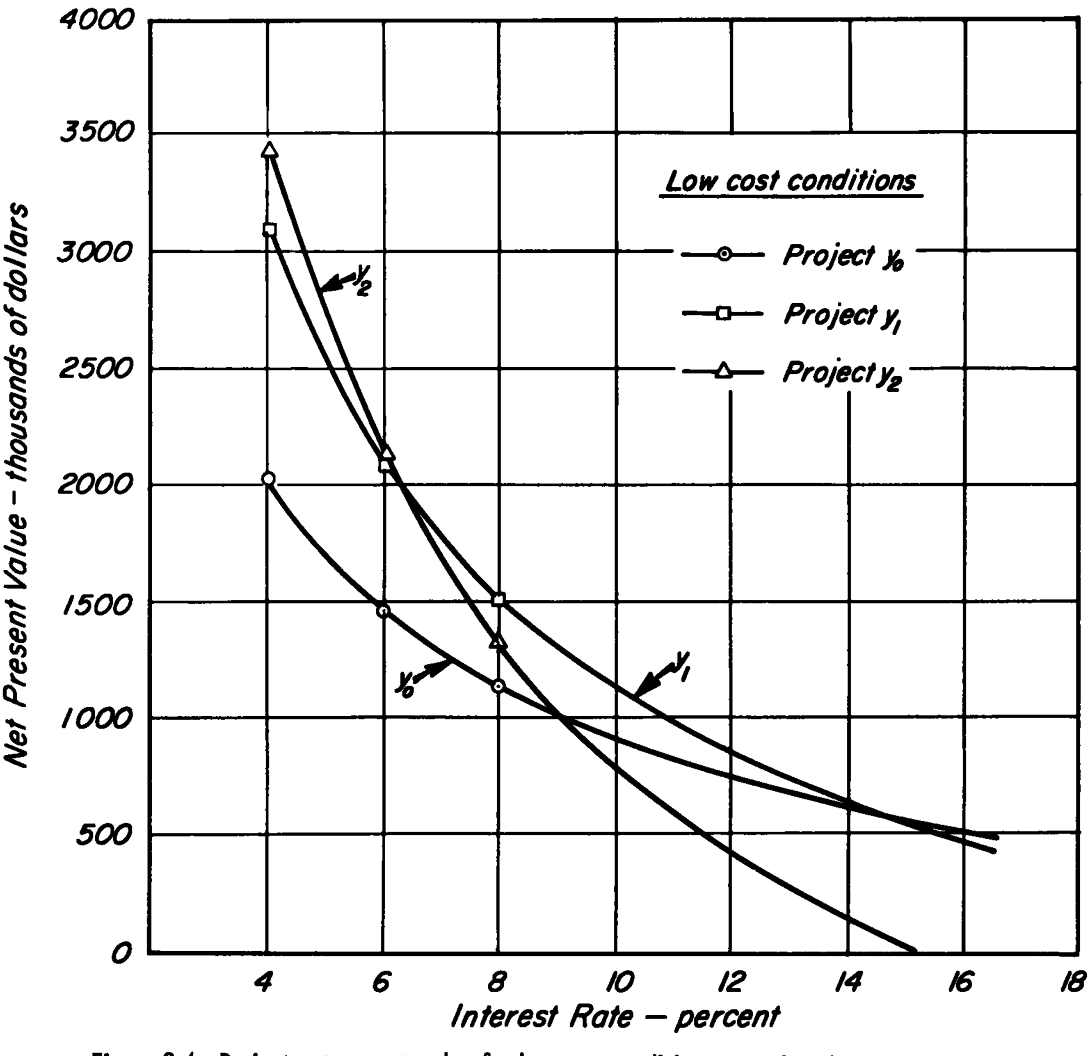

Figure 3.4. Project net present value for low cost conditions at various interest rates.

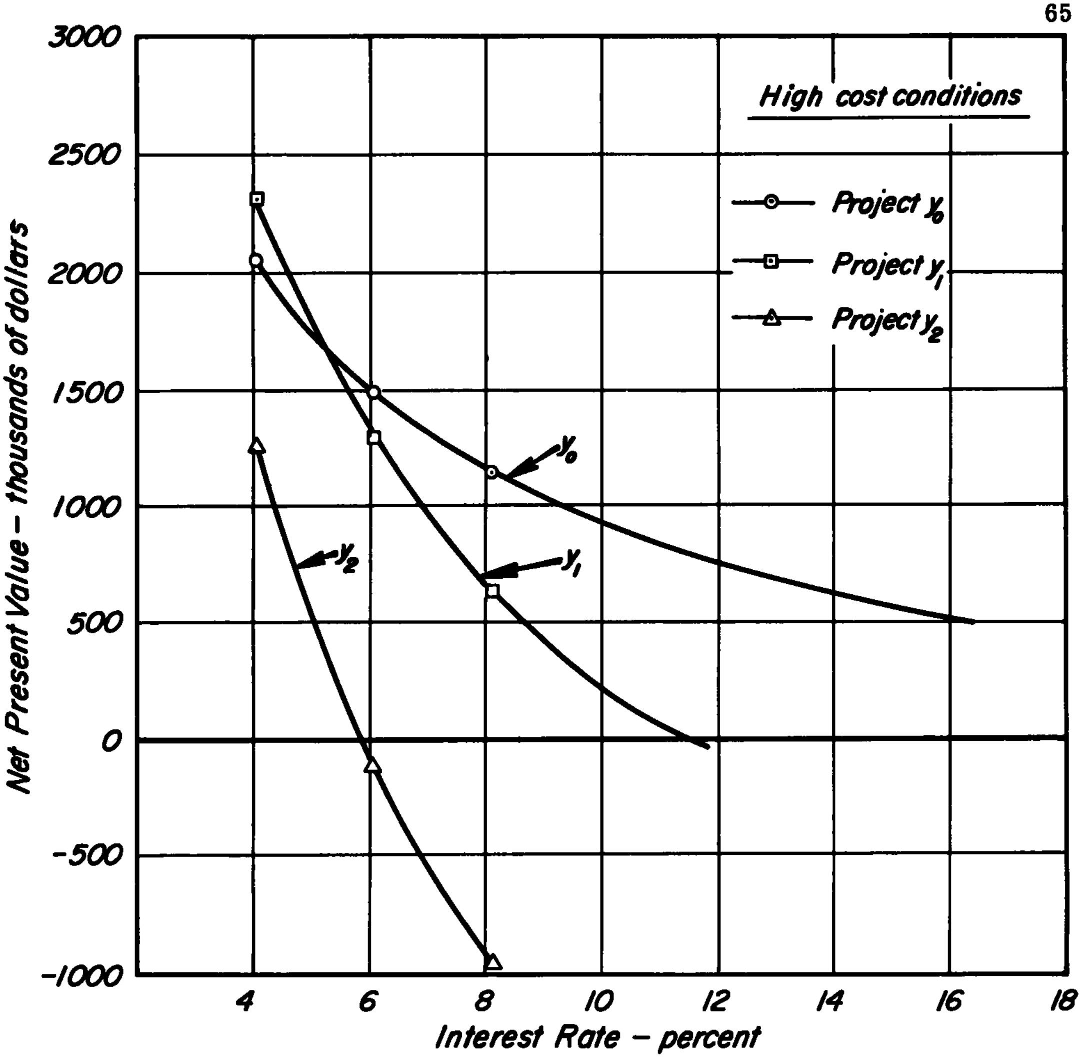

Figure 3.5. Project net present value for high cost conditions at various interest rates.

TABLE 3.5

NET PRESENT VALUE OF PROJECTS ANALYZED*
(in $1000's)

Interest Rate for Computing Net Present Value (%)	Net Present Value (in $1,000's)					
	Low Cost Projects			High Cost Projects		
	y_0	y_1	y_2	y_0	y_1	y_2
4	2,026	3,078	3,405	2,026	2,298	1,217
6	1,491	2,104	2,121	1,491	1,284	(-110)
8	1,146	1,475	1,295	1,146	637	(-957)

*Best project (or that of highest positive net present value) for each interest rate and within each high or low cost grouping is underlined.

For low cost conditions, project y_2 would be most desirable at interest rates of 6 percent or below while project y_1 would be the best alternative for interest rates within the general range of 6 to 14 percent; above 14 percent, the existing situation or null alternative (project y_0) would appear most attractive.

For high cost conditions, however, the high initial capital outlays of project y_2 all but rule it out as a possibility, at least so long as the relevant interest rate or cost of capital is 4 percent or above. While project y_1 does appear to be the best alternative at the 4 percent level, its capital outlays cause it to lose attractiveness quickly as the interest rate increases; as a result, at interest rates of about 5 percent or above the existing facility or project y_0 will be the best project.

The effect of increasing the unit capital costs for construction and land acquisition can be noted by observing the downward shifts of the project y_1 and y_2 curves in moving from the low cost to high cost situations (see Figs. 3.4 and 3.5) while the project y_0 curve maintains a more constant position. Further, in these particular cases, as the capital costs rise the effects of increases in the interest rate are more pronounced.

3.3.2. Discounted Rate-of-Return Calculations

To repeat, the rate-of-return is that rate of interest or discount rate at which the discounted project costs just equal the discounted project benefits. In virtually all economic analyses, the rate-of-return can only be determined by trial-and-error-type calculations, usually using Newton's approximation; that is, the appropriate interest will be estimated and the discounted costs and benefits applying to that interest rate will be computed. If the discounted costs just equal the benefits, the estimated interest rate will be the rate-of-return; if not, another trial interest rate must be selected, and another set of calculations undertaken—and so forth, until the proper rate is determined.

To determine the discounted rate-of-return for each of the projects will first require a set of calculations identical to those just undertaken for the present value method. Furthermore, since the analyst seldom will be fortunate enough to have chosen the correct interest rate during the first trial, more than one set of calculations must be endured and thus the computations, time, and effort required for this analysis method will virtually always exceed that of the net present value method.

Once the analyst has determined the rate-of-return for each project as a whole (that is, he has determined that interest rate for which the discounted costs for the project just balance the discounted benefits for the project), he has only answered the question of "whether to accept or reject the project as a whole" or of "whether to do it at all." He has not determined, however, which way is best or a ranking of the acceptable projects.

The latter question can be answered only by examining the rate-of-return on the incremental costs and benefits associated with successively higher cost projects. That is, any additional cost over that of the lowest cost acceptable project can be justified only if the rate-of-return on the additional cost is at least as high as the cost of capital (or minimum attractive return).

Computationally, the analyst must examine the next most costly project and must determine that rate of interest at which the discounted additional costs (over the next lowest cost and acceptable alternative) just equal the discounted additional benefits. If the incremental rate-of-return is acceptable (that is, if the incremental rate-of-return is at least as high as the cost of capital), then the net present value of the higher cost alternative will be at least as high as that of the lower cost alternative to which it is being compared. Or, conversely, if the net present value (as computed at the cost of capital) of the higher cost alternative is at least as high as that of the lower cost alternative then necessarily the rate-of-return on the additional costs must be at least as high as the cost of capital, and therefore the more costly alternative is better than the less costly one.

In other words, by merely examining the net present value calculations we can determine whether or not the return on the incremental costs is satisfactory. The net present value can increase only if the benefits exceed the costs and thus only if the

TABLE 3.6

NET PRESENT VALUE FOR
THE HIGH COST VERSION OF PROJECT y_2

Interest Rate (%)	Net Present Value ($)
4	1,217,000
5½	105,000
6	(-110,000)

rate-of-return is greater than the cost of capital; and by the same token, a decrease in net present value with an increase in costs means that the rate-of-return on the additional cost is less than the cost of capital.

These points can be demonstrated by examining the data for the high cost version of project y_2, relative to the other alternatives. The first step is to determine the rate-of-return for project y_2 and to compare it with the cost of capital. From the net present value figures in Appendix 3.10 or Figure 3.5, it can be seen that at an interest rate of 4 percent the discounted benefits are larger than the discounted costs, while at 6 percent the discounted costs outweigh the discounted benefits. Consequently, we know that the rate-of-return is between 4 and 6 percent.[100] Further, if we compute the discounted benefits and costs at an interest rate of 5½ percent, we find that the net present value is positive, but quite low. Three sets of results for project y_2 were as given in Table 3.6. If one interpolates between the sets of numbers, the rate-of-return for the high cost version of project y_2 can be estimated as 5.8 percent.

High cost project y_2 will be acceptable, though not necessarily the best alternative of the group, so long as the cost of capital or minimum attractive rate-of-return is equal to or less than 5.8 percent. (For the cases we examined, this project would be unacceptable and thus rejected at interest rates of 6 and 8 percent.) Next, the additional costs and benefits can be discounted at various interest rates to determine the rate-of-return on the incremental costs. Rather than carry out these computations, it is only necessary to examine the changes in net present value between acceptable projects of lower and higher cost at the cost of capital. For example, assume that the cost of capital is 4 percent; in that case, project y_1 is the least costly of the three, project y_0 is that of next higher cost, and project y_2 is the most costly. Since at 4 percent all projects are acceptable (that is, all projects have a rate-of-return greater than 4 percent), we must first compare project y_0 to project y_1 (i.e., we are examining the first increment of costs and benefits). The net present value falls, as the costs increase in moving from project y_1 to y_0, and therefore the rate-of-return on the incremental costs is less than the cost of capital; consequently, project y_2 is then compared to y_1, the next less costly alternative which is acceptable. However, since the net present value decreases as we move from a lower to a higher cost alternative, the incremental rate-of-return must necessarily be less than the cost of capital. Therefore, project y_2 must be rejected.

The rate-of-return on the three projects and for high and low cost conditions are shown in part II of Appendix 3.10; also, we have noted whether or not the rates-of-return on the incremental costs of successively higher cost alternatives are at least as high as the cost of capital for rates of 4, 6, and 8 percent.

3.3.3. Annual Cost Calculations

This method calls for determining the annual facility and user costs for an equivalent annual or representative year, and for selecting that alternative of lowest annual cost. Importantly, the method is entirely valid only when alternatives of identical benefit are being compared; that is, the method will generally prove valid only when alternatives being compared will have the same future volumes and travel speed or service conditions. Since alternative projects seldom can be expected to experience identical volumes and total user benefits, the method will seldom be helpful.

---

[100] As pointed out earlier, it is possible for multiple rates-of-return to result. However, we shall assume that only one rate-of-return is possible in this case. Where multiple rates exist, outside information must be used to select the correct solution from those available.

Since both the volumes and travel conditions (and benefits) on the projects being compared in this example are not equal, the annual cost method will give improper results, as will be shown.[101] Furthermore, inasmuch as this example would appear to be a typical one and more realistic than the usual economic analysis example which indicates and assumes equal and constant annual volumes on all alternatives, it must be concluded that the annual cost method generally should not be used for engineering economy studies.

The major problem in determining annual costs is the reduction of the cost data to an "equivalent annual" basis or to an "equivalent uniform annual series of payments." In simplest terms, the equivalent uniform annual series of payments for any cost item may be determined by:

1. Determining the present value of the cost item at the cost of capital; and
2. Multiplying the present value of the cost item (i.e., the discounted cost) times the so-called "capital recovery factor" or sinking fund factor plus the interest rate.

Analytically, the equivalent annual cost for any cost item or group of cost items can be expressed as follows:

$$EAC_{i,n} = PVC_{i,n}(crf_{i,n}) \tag{3.24}$$

$$= PVC_{i,n}\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \tag{3.25}$$

$$= PVC_{i,n}(sff_{i,n} + i) \tag{3.26}$$

$$= PVC_{i,n}\left[\frac{i}{(1+i)^n - 1} + i\right] \tag{3.27}$$

where $EAC_{i,n}$ is the equivalent uniform annual cost, computed for interest rate of i (percent over 100) and a terminal date of n years; $PVC_{i,n}$ is the total present value of all costs occurring over the n-year period and discounted to the present at an interest rate of i; also, $crf_{i,n}$ is the capital recovery factor and $sff_{i,n}$ is the sinking fund factor.

Since all of the cost items of our example (to include facility construction, right-of-way, maintenance and administration, and user costs) have already been discounted to their present value for interest rates of 4, 6, and 8 percent, the equivalent annual cost for each project and interest rate can be determined simply by multiplying the total discounted costs times the appropriate capital recovery factor (in this case, that for a 40-year period and either 4, 6, or 8 percent interest). For example, the total discounted costs for project y_0 (either the low or high cost version) at a 4 percent interest rate was \$77.544 million (as shown in part I of Appendix 3.10); this figure times the capital recovery factor of 0.05052 (for 4 percent and 40 years) results in an equivalent annual cost of \$3.917 million, as shown in part III of Appendix 3.10.

Crucially, though, if the results of the equivalent annual cost method (whereby the alternative of lowest equivalent annual cost is selected as the best project) are compared with either the present value or rate-of-return results in parts I and II of Appendix 3.10, it will be clear that the annual cost project selections differ in some cases with those of the other two methods. As shown more simply in Table 3.7, the annual cost method would result in an improper project selection in four out of the six cases examined.

---

[101] This is not a general statement, but applies for this particular analysis and for these data (or for other similar situations).

TABLE 3.7

BEST ACCEPTABLE PROJECT FOR COST CONDITION, INTEREST RATE AND ANALYSIS METHOD

	Best Project According to:			
Interest Rate (%)	Present Value Method	Rate of Return Method	Annual Cost Method	Benefit-Cost Ratio Method
Low cost conditions:				
4	y_2	y_2	y_1	y_2
6	y_2	y_2	y_1	y_2
8	y_1	y_1	y_1	y_1
High cost conditions:				
4	y_1	y_1	y_1	y_1
6	y_0	y_0	y_1	y_0
8	y_0	y_0	y_1	y_0

3.3.4. Benefit-Cost Ratio Calculations

The benefit-cost ratio calculations must be carried out in two steps, much like the rate-of-return method. First, ratios must be computed for the overall project, and, second, ratios must be computed on the incremental benefits and costs of increasingly higher cost projects.

The so-called benefit-cost ratio is an arbitrary ratio of the benefits to the costs, the latter two items being placed either on a discounted (or present value) basis or on an equivalent uniform annual basis, according to one's preference. (Mathematically, of course, the ratios computed either way would be equal.) More importantly, the convention is arbitrary with respect to the classification or specification of what items are to be called benefits; for example, usually engineers do not make the same distinction between costs and benefits as do the economists, but will regard reductions in user costs as benefits and will therefore place these reductions or negative costs (if any) in the numerator. Also, reductions in highway maintenance costs will sometimes be called benefits, and placed in the numerator, though more often they are retained as costs and kept in the denominator.

One should recognize that the usual way of treating benefits and costs in the highway engineering literature ordinarily is not a good policy. First, with improvement of a roadway or in a corridor, it is reasonable to expect reductions in the unit user cost or user cost per mile of travel but it is also reasonable to expect increases in the volume of usage because of the reductions in unit travel costs. This volume increase may well result in the total user costs being increased with improvements, just as we experienced with the example problem. For example, the unit travel cost for project y_2 was less than that for project y_0, but the overall or total discounted user costs for project y_2 were higher than those for project y_0 at the three levels of interest we analyzed. In other words, if differences in volume of usage which will or may result from travel improvements are recognized, then the usual definition of highway benefits may result in a negative amount of benefit, unless one always restricts his attention to equal amounts of volume usage, and thus less congestion and travel cost than it is realistic to consider.

It is important to note that none of these problems arise when a definitional framework of the sort proposed herein is followed.

Computationally, the benefit-cost ratio for a project or the ratio applying to an increment of cost between two projects applies only for a specified terminal date and

TABLE 3.8

EQUIVALENT ANNUAL COSTS AND BENEFITS, AND BENEFIT-COST RATIOS FOR LOW-COST PROJECTS

Low-Cost Project	Equivalent Annual Benefits (in $millions)	Equivalent Annual Costs (in $millions)	Benefit-Cost Ratio for Overall Project	Benefit-Cost Ratio for Increment of Cost and Benefit Over Next Less Costly Project
y_0	4.020	3.918	1.03	0.951 (for y_0 to y_1)
y_1	2.985	2.829	1.05	—
y_2	4.356	4.184	1.04	1.012 (for y_2 to y_1)

interest rate, just as with the present value and annual cost methods. As an example, consider the circumstances for the low-cost projects at 4 percent over 40 years; just as with the annual cost method, the equivalent annual costs or benefits can be computed by multiplying the discounted costs or benefits (given in part I of Appendix 3.10) times the appropriate capital recovery factor (or, $crf_{4,40}$ in this case) of 0.05052. For the low-cost projects at 4 percent, the resultant equivalent annual costs and benefits are given in Table 3.8, along with the benefit-cost ratios for overall projects and their increments. For project y_0, for example, the overall ratio is $4.020 million divided by $3.918 million or a ratio of 1.03, and so forth. Once each ratio is computed, all projects having a ratio of at least 1.0 are regarded as acceptable projects; then, the ratio must be computed for increments of cost over the next less costly acceptable project. In this case, project y_1 is the lowest cost project that is acceptable and must be used for examining the benefit-cost ratio for the incremental costs for the next most costly project, which in this case is y_0. The ratio for the increment between y_1 and y_0 is simply the difference between the overall benefits of the two (or $4.020 million minus $2.985 million) divided by the difference between the overall costs (or $3.918 million minus $2.829 million); thus the ratio is 1.035/1.089 or 0.951. Since the ratio for the increment of cost is less than one, the additional cost is not justified and the project is rejected. Once project y_0 is eliminated, the next most costly project relative to project y_1 is project y_2, of course. Computing the ratio for its increment of cost, it would be the difference in benefits (or $1.371 million) divided by the difference in costs (or $1.355 million), or a ratio of 1.012. Since the ratio for this increment is greater than one, the increment of cost is justifiable and the more costly project (y_2) is the best alternative.

3.4 IMPLICATIONS OF PRECEDING ANALYSES

For this particular example problem, the net present value, rate-of-return and benefit-cost ratio methods of analysis all indicated the same results in selecting the best acceptable project (Table 3.7). The annual cost method, however, produced inconsistent results because the method does not take into account benefits or differences in benefits (from project to project); thus, in situations of this sort the annual cost method should not be used.

Even though the net present value and rate-of-return methods selected the same set of projects as best for this example, it is important to emphasize that such a result occurred only by accident! Had the cost and benefit streams over the 40-year period of analysis been somewhat different, the results could easily have been conflicting;

again, this possibility stems from the fact that the net present values are computed while assuming that the reinvestment rate (for the annual earnings or benefits) is equal to the cost of capital or discount rate, while the rate-of-return figures are computed while assuming that the reinvestment rate is equal to the computed rate-of-return. Thus, we must re-emphasize the caution that must be exercised with regard to use of the rate-of-return method; it can easily give misleading results for economic feasibility decisions.

Finally, it should be noted that even though for the special set of assumptions made for this particular example problem our analysis could have been shortened and simplified considerably (by simply analyzing the various levels of discounted user taxes and facility costs), the full-scale analysis was carried out. This was done principally because in the general case it will not be possible to ignore certain interactions between the facility design and vehicle operating costs, etc., and it was felt useful to include the entire procedure to be followed in more general circumstances. In short, the procedure as it was followed herein can be used to analyze the effects of any type of design problem—whether consumer surplus is included or not, and whether tripmaking benefits are affected by design changes or not; thus the analysis method is not restricted to special case situations which is so often the case in the engineering economy literature.

3.5 CHANGES TO PREVIOUS ANALYSES IF CONSUMER SURPLUS IS INCLUDED

The benefit totals included in this chapter and the accompanying appendices (and the measures of economy resulting therefrom) did not include consumer surplus, and thus do not include any portion of the benefit which travelers do receive but did not actually pay for. The practical result was that any facility expenditures which either did not reduce other resource costs by a corresponding amount or did not increase the allowable benefit (not including consumer surplus) as much will result in economic infeasibility.[102]

Should one have judged it appropriate to include consumer surplus in the benefit totals, the preceding economic analyses would have been changed in only one respect. And that is, the benefit totals indicated in Appendices 3.4, 3.6 and 3.10 would have been increased by the amount of the consumer surplus. As pointed out in Section 1.3.3 and the accompanying Table 1.2, the benefit totals would have to be increased to include the area above and to the left of the user price and underneath the demand curve. Referring to Figure 3.2, and to the situation for project y_1 during off-peak hours in year 1, the benefit totals in our analyses include only the area to the left of and below the price indicated at point A; the consumer surplus is the area to the left of and above point A and underneath the demand curve (only part of which is sketched in Figure 3.2). Consequently, if one does include consumer surplus in the benefit totals, it is necessary to have full knowledge of the demand curve over its entire range. (In our case, it was only necessary to have knowledge in the region of actual tripmaking.)

Some analysts would argue that it is not necessary to have full knowledge of the demand curve over its full range but only for the interval between alternatives; that is, they would argue that our interest is only in the change in consumer surplus (or what we previously termed change in net benefit) between alternatives. More specifically, they would note that our interest is confined to the change in consumer surplus between alternatives, say, y_0 and y_1; thus for off-peak hours and year 1, they would argue that it is only necessary to determine the change in net benefit (that is, change in consumer

---

[102] It is important to emphasize, though, that the benefit totals are directly related to the user tax price—as noted in Section 3.2.4. Thus, it is possible for a project to be indicated as economically infeasible at, say, existing user tax levels but to be feasible at another either higher or lower level; this could certainly be the case when the user tax level used in the analysis was not at the unit elastic point. In short, the engineer should as a practical matter consider the user tax level to be an independent variable subject to change (just as any other design variable).

surplus) within the shaded area associated with points A and B (see Figure 3.2). However, as emphasized repeatedly, if the economic analysis is restricted to these increments of consumer surplus (and the increments of expenditure associated with them), the engineer will succeed in answering only the question of "Which way is best" and will not answer the equally important question of "Whether to do it at all." That is, the possibility always exists of abandoning project y_0 altogether (and thus of having no benefits and no costs); and if project y_0 in total has a negative net present value or less than attractive rate-of-return, then clearly to do nothing is economically preferable to operating the existing facility.[103]

In conclusion, if one does include consumer surplus in the benefit totals, he is left with the dubious possibility of having to determine the demand curve over its full range or with that of having to carry out an incomplete economic analysis.

3.6 ANALYSES FOR CERTAIN TYPES OF DESIGN CHANGES WHICH DO NOT AFFECT TRIPMAKING OR BENEFITS

Earlier it was noted that additional facility expenditures can be justified not only on the basis of increased user tripmaking or benefit but also can be justified by bringing about reductions in other resource costs. For example, improvements in roadway design may reduce tire wear or gasoline consumption or accidents but may not affect the demand and perceived user price-volume relationships (and thus the level of user tripmaking or benefits).[104] In other words, the actual user travel costs will be reduced but travelers will not perceive these savings in their tripmaking calculus. In instances such as these, the analyst should make a distinction between the perceived user travel prices and the actual user travel costs, item by item.

For these sorts of situations, the analysis is simplified considerably—in that the benefit side of the economic analysis can be ignored for the purpose of determining the best among several types or levels of physical facility designs; again, though, this type of analysis will not be concerned with the acceptability of the possible physical designs, or whether to undertake the project at all, a question that must still be answered by the analyst at some stage in the overall decision-making analysis.

For making these kinds of analyses, it will be necessary to examine the increments of facility expenditure or cost over the lowest cost possibility (for a particular project) and to determine what changes in non-perceived user travel cost (or other public costs) are associated with the specific design changes. As noted before in Table 1.1, the particular cost items of interest are the following:

1. Facility construction and land acquisition costs;
2. Dislocation and other social costs;
3. Facility operation, maintenance and administration costs;
4. User travel costs, to include: (a) vehicle ownership costs (excluding all fees and taxes, (b) vehicle operating and maintenance costs (excluding all fees and taxes), (c) time costs, (d) discomfort costs, and (e) inconvenience costs;
5. Accident costs; and
6. Terminal (parking and garaging) costs.

To the extent that changes in any of these costs do not affect the perceived user price, and thus the amount of tripmaking and benefit, we can examine the economic consequences of changing the facility design and thus reducing these costs without considering the tripmaking benefits.

---

[103] In such an instance, the overall economy of the next higher cost alternative would have to be examined to determine if it is preferable to complete abandonment. Once an overall project has been found to be economically attractive, then it is necessary to examine only increments of investment for successively higher cost alternatives.

[104] In essence, this becomes a problem of determining the most efficient technology for performing a certain production function. In other words, what is the most efficient combination of pavement, grades, alignment, etc., for handling a specified level of volume at a given level of (perceived) service.

To be more specific, by changing the type of roadway surface or its alignment, etc., changes in the facility costs (either construction, land acquisition or continuing) can be anticipated on the one hand and (hopefully) reductions in certain vehicle operating or accident costs on the other—the latter of which will not be perceived by the traveler. Only the increments of cost, properly signed (positive or negative), need be included in the incremental economic analysis. Thus, one may view this sort of analysis as one consisting of an examination of the increments of annual cost or increments of net present value (wherein the benefits for the alternative designs are equal and thus net out to zero); consequently, all design changes which result in a negative increment in annual cost or net present value will represent better designs and should be substituted for the next lowest cost (and acceptable) design.

Finally, it should be pointed out that all other details of this incremental cost analysis would be similar to the procedures outlined in previous sections, that is, the particular costs should be computed by year for both peak and off-peak periods (where they differ as vehicle speeds change) and should employ all of the appropriate discounting techniques outlined.

Appendix

APPENDIX 3.1

AV-ANNUAL VOLUMES ON FACILITIES SHOWN*

Year	AV-Annual Volumes			
	y_0	y_1	y_{2_N}	y_{2_E}
0	13. 5	16. 5	9. 75	9. 000
1	13. 8	16. 987	10. 125	9. 2625
2	14. 1	17. 475	10. 5	9. 525
3	14. 4	17. 962	10. 875	9. 7875
4	14 7	18. 45	11. 25	10. 05
5	15. 0	18. 937	11. 625	10. 3125
6	15. 3	19. 425	12. 0	10. 575
7	15. 6	19. 913	12. 375	10. 8375
8	15. 9	20. 4	12. 75	11. 1
9	16. 2	20. 887	13. 125	11. 3625
10	16. 5	21. 375	13. 5	11. 625
11	16. 8	21. 862	13. 875	11. 8875
12	17. 1	22. 350	14. 25	12. 15
13	17. 4	22. 837	14. 62	12. 4125
14	17. 7	23. 325	15. 0	12. 675
15	18. 0	23. 812	15. 375	12. 9375
16	18. 3	24. 30	15. 75	13. 2
17	18. 6	24. 787	16. 125	13. 4625
18	18. 9	25. 275	16. 5	13. 725
19	19. 2	25. 762	16. 875	13. 9875
20**	19. 5	26. 25	17. 25	14. 25

*In millions of vehicle trips, based on Eqs. 3.1 through 3.4.

**20 and over.

APPENDIX 3.2

HOURLY LANE VOLUMES ON FACILITIES*

Year	Existing Facility (y_0)		Improved Facility (y_1)		New Facility (y_{2_N})		Existing Roadway (y_{2_E})	
	Peak Hour (q_p)	Off-Peak Hour (q_o)	Peak Hour (q_p)	Off-Peak Hour (q_o)	Peak Hour (q_p)	Off-Peak Hour (q_o)	Peak Hour (q_p)	Off-Peak Hour (q_o)
1	936	450	1152	553	687	330	628	301
2	946	461	1173	571	705	343	639	312
3	957	473	1193	590	723	357	650	322
4	966	484	1213	608	740	371	661	331
5	976	497	1232	627	756	385	671	341
6	985	508	1250	645	773	398	681	351
7	994	520	1268	664	788	412	690	361
8	1002	532	1285	683	803	426	699	372
9	1010	544	1302	702	818	441	708	382
10	1017	556	1317	721	832	455	717	392
11	1024	569	1333	740	846	470	725	402
12	1031	580	1347	759	859	484	732	412
13	1037	593	1361	779	871	499	740	423
14	1043	605	1374	798	884	513	747	434
15	1048	617	1386	818	895	527	753	444
16	1053	630	1398	838	906	542	759	455
17	1057	644	1409	857	917	557	765	465
18	1062	656	1420	878	927	573	771	476
19	1065	669	1429	897	936	588	776	487
20**	1068	682	1438	918	945	603	780	499

*Based on data in Appendix 3.1 and Eqs. 3.10 and 3.11.
**20 and over.

APPENDIX 3.3

AVERAGE PEAK AND OFF-PEAK SPEEDS*

Year	Existing Facility (y_0)		Improved Facility (y_1)		New Facility (y_{2_N})		Existing Roadway (y_{2_E})	
	Peak Hour	Off-Peak Hour	Peak Hour	Off-Peak Hour	Peak Hour	Off-Peak Hour	Peak Hour	Off-Peak Hour
1	18.8	25.2	41.8	55.4	58.3	64.4	22.8	27.1
2	18.7	25.0	41.4	54.0	58.0	64.2	22.7	26.9
3	18.6	24.9	40.9	53.6	57.7	63.9	22.6	26.8
4	18.4	24.7	40.5	53.2	57.4	63.7	22.4	26.7
5	18.3	24.5	40.1	52.8	57.1	63.5	22.3	26.6
6	18.2	24.4	39.7	52.4	56.9	63.2	22.1	26.4
7	18.1	24.2	39.4	52.0	56.6	63.0	22.0	26.3
8	18.0	24.1	39.0	51.6	56.3	62.8	21.9	26.2
9	17.9	23.9	38.7	51.3	56.1	62.5	21.8	26.0
10	17.8	23.8	38.3	50.8	55.9	62.3	21.7	25.9
11	17.7	23.6	38.0	50.5	55.6	62.0	21.6	25.8
12	17.6	23.5	37.7	50.1	55.4	61.8	21.5	25.6
13	17.5	23.3	37.4	49.6	55.2	61.5	21.4	25.5
14	17.4	23.1	37.1	49.2	55.0	61.3	21.3	25.4
15	17.4	23.0	36.9	48.8	54.8	61.0	21.2	25.2
16	17.3	22.8	36.6	48.4	54.6	60.8	21.1	25.1
17	17.3	22.6	36.4	48.0	54.4	60.5	21.1	25.0
18	17.2	22.5	36.2	47.5	54.2	60.3	21.0	24.8
19	17.2	22.3	36.0	47.2	54.1	60.0	20.9	24.7
20**	17.1	22.1	35.8	46.7	53.9	59.7	20.9	24.5

*Based on data in Appendix 3.2, and Eq. 3.14 plus parameter values from Eqs. 3.5 through 3.7.
**20 and over.

APPENDIX 3.4

ANNUAL USER TRIPMAKING BENEFITS PER MILE FOR PEAK AND OFF-PEAK PERIODS (in $1000's)

Year	Existing Facility (y_0)		Improved Facility (y_1)		New Facility (y_2)		Existing Roadway (y_2)	
	Peak Hour	Off-Peak Hour	Peak Hour	Off-Peak Hour	Peak Hour	Off-Peak Hour	Peak Hour	Off-Peak Hour
(a) Breakdown of Annual Benefits by Peak and Off-Peak Periods								
1	978	2088	677	1510	336	835	574	1330
2	992	2149	689	1585	345	876	584	1385
3	1007	2216	711	1637	357	911	597	1437
4	1025	2278	723	1701	365	947	609	1477
5	1039	2350	739	1754	373	983	621	1529
6	1053	2402	755	1819	385	1016	633	1582
7	1066	2482	771	1872	392	1061	645	1627
8	1079	2540	786	1941	400	1097	656	1685
9	1092	2609	797	1995	407	1136	667	1739
10	1108	2679	811	2094	417	1172	676	1785
11	1120	2754	827	2119	424	1210	686	1839
12	1132	2820	841	2191	431	1257	696	1894
13	1142	2897	855	2248	437	1296	706	1944
14	1153	2982	863	2321	447	1333	713	2004
15	1159	3041	876	2397	453	1369	722	2060
16	1169	3133	890	2456	458	1420	731	2121
17	1173	3217	897	2531	464	1459	737	2168
18	1183	3292	909	2612	473	1501	746	2230
19	1186	3372	915	2669	477	1540	754	2292
20*	1198	3452	927	2751	482	1593	757	2360
(b) Total Annual Benefits for Peak and Off-Peak Travel								
1	3066		2187		3075			
2	3141		2274		3190			
3	3223		2348		3302			
4	3303		2424		3398			
5	3389		2493		3506			
6	3455		2574		3616			
7	3548		2643		3725			
8	3619		2727		3838			
9	3701		2792		3949			
10	3787		2905		4050			
11	3874		2946		4159			
12	3952		3032		4278			
13	4039		3103		4383			
14	4135		3184		4497			
15	4200		3273		4604			
16	4302		3346		4740			
17	4390		3428		4828			
18	4475		3521		4950			
19	4558		3584		5063			
20*	4650		3678		5192			
0-20	$\sum$ = 76807		$\sum$ = 58462		$\sum$ = 82343			
21-40	$\sum$ = 93000		$\sum$ = 73560		$\sum$ = 103840			

*20 and over.

APPENDIX 3.5

USER TRIPMAKING PRICES PER VEHICLE TRIP*
(in cents per trip)

Year	Existing Facility (y_0)		Improved Facility (y_1)		New Facility (y_2)		Existing Roadway (y_3)	
	Peak Hour	Off-Peak Hour	Peak Hour	Off-Peak Hour	Peak Hour	Off-Peak Hour	Peak Hour	Off-Peak Hour
1	25.6¢	20.9¢	14.4¢	12.3¢	12.0¢	11.4¢	22.4¢	19.9¢
2	25.7	21.0	14.4	12.5	12.0	11.5	22.4	20.0
3	25.8	21.1	14.6	12.5	12.1	11.5	22.5	20.1
4	26.0	21.2	14.6	12.6	12.1	11.5	22.6	20.1
5	26.1	21.3	14.7	12.6	12.1	11.5	22.7	20.2
6	26.2	21.3	14.8	12.7	12.2	11.5	22.8	20.3
7	26.3	21.5	14.9	12.7	12.2	11.6	22.9	20.3
8	26.4	21.5	15.0	12.8	12.2	11.6	23.0	20.4
9	26.5	21.6	15.0	12.8	12.2	11.6	23.1	20.5
10	26.7	21.7	15.1	12.9	12.3	11.6	23.1	20.5
11	26.8	21.8	15.2	12.9	12.3	11.6	23.2	20.6
12	26.9	21.9	15.3	13.0	12.3	11.7	23.3	20.7
13	27.0	22.0	15.4	13.0	12.3	11.7	23.4	20.7
14	27.1	22.2	15.4	13.1	12.4	11.7	23.4	20.8
15	27.1	22.2	15.5	13.2	12.4	11.7	23.5	20.9
16	27.2	22.4	15.6	13.2	12.4	11.8	23.6	21.0
17	27.2	22.5	15.6	13.3	12.4	11.8	23.6	21.0
18	27.3	22.6	15.7	13.4	12.5	11.8	23.7	21.1
19	27.3	22.7	15.7	13.4	12.5	11.8	23.8	21.2
20	27.5	22.8	15.8	13.5	12.5	11.9	23.8	21.3

*Based on a one-mile trip, and determined from Eqs. 3.5 through 3.7, together with hourly volume data from Appendix 3.2.

APPENDIX 3.6

DISCOUNTED ANNUAL USER TRIPMAKING BENEFITS PER MILE*
(in $1000's)

Year	Existing Facility (y_0)			Improved Facility (y_1)			New Facility Plus Existing (y_2)		
	4%	6%	8%	4%	6%	8%	4%	6%	8%
1	2948	2892	2839	2103	2063	2025	2957	2901	2847
2	2903	2795	2693	2102	2024	1949	2949	2839	2735
3	2865	2706	2558	2087	1971	1864	2935	2772	2621
4	2823	2616	2428	2072	1920	1782	2905	2691	2498
5	2785	2532	2306	2049	1863	1697	2882	2620	2386
6	2730	2436	2177	2034	1815	1622	2858	2549	2279
7	2695	2360	2070	2008	1758	1542	2831	2477	2174
8	2644	2270	1955	1993	1711	1473	2804	2408	2074
9	2600	2191	1851	1962	1653	1397	2774	2337	1975
10	2558	2115	1754	1963	1622	1346	2736	2262	1876
11	2516	2041	1661	1914	1552	1264	2702	2191	1784
12	2468	1964	1569	1894	1507	1204	2672	2126	1699
13	2426	1893	1485	1864	1455	1141	2632	2055	1612
14	2388	1829	1408	1839	1408	1084	2597	1989	1531
15	2332	1753	1324	1817	1366	1032	2557	1921	1451
16	2297	1693	1256	1786	1317	977	2531	1866	1384
17	2254	1630	1187	1760	1273	928	2479	1793	1305
18	2209	1566	1119	1738	1233	881	2443	1734	1238
19	2163	1506	1056	1701	1185	830	2403	1673	1173
20	2122	1450	997	1679	1147	789	2370	1619	1114
Σ 21-40	28844	16628	9798	22815	13153	7750	32206	18567	10940
Σ 0-40	79570	58866	45491	59080	44996	34577	86223	63490	48696

*Based on data in Appendix 3.4, but discounted using a single-payment present value factor for years 1 through 20, and a uniform series present value factor for years 21 through 40, for the former $pwf'_{i,t} = \frac{1}{(1+i)^t}$; for the latter $pwf_{i,40-20} = \frac{(1+i)^{40}-1}{i(1+i)^{40}} - \frac{(1+i)^{20}-1}{i(1+i)^{20}}$.

APPENDIX 3.7

DISCOUNTED HIGHWAY MAINTENANCE & ADMINISTRATIVE COSTS PER MILE*
(in $1000's)

Project		4%	6%	8%
Existing, y_0	0-20 years	608	512	440
	21-40 years	276	160	92
	Total	884	672	532
Improved, y_1	0-20 years	428	364	312
	21-40 years	196	112	68
	Total	624	476	380
New road plus existing, y_2	0-20 years	864	732	636
	21-40 years	392	224	132
	Total	1256	956	768

*Based on data from Table 3.2 and using uniform series present value factor as shown in Eqs. 3.16 and 3.17.

APPENDIX 3.8

DISCOUNTED CONSTRUCTION AND ROADWAY COSTS* PER MILE
(in $1,000's)

Project		Low Costs			High Costs		
		4%	6%	8%	4%	6%	8%
Existing, y_0	Construction	–	–	–	–	–	–
	Initial roadway	–	–	–	–	–	–
	Roadway salvage	–	–	–	–	–	–
Improved, y_1	Construction	600	600	600	1,100	1,100	1,100
	Initial roadway	–	–	–	354	354	354
	Roadway salvage	–	–	–	(-)74	(-)34	(-)16
	Net roadway				280	320	338
New road plus existing, y_2	Construction	876	876	876	2,752	2,752	2,752
	Initial roadway	394	394	394	788	788	788
	Roadway salvage	(-)82	(-)38	(-)18	(-)164	(-)77	(-)36
	Net roadway	312	356	376	624	711	752

*Initial right-of-way costs less roadway discounted from fortieth year, assuming entire roadway cost is salvageable at that date, data from Table 3.2.

APPENDIX 3.9

DISCOUNTED USER TAXES* PER MILE
(in $1000's)

Project		Rate		
		4%	6%	8%
Existing, y_0	initial for 40 years	2324	1767	1400
	gradient 0 to 20	285	223	176
	gradient 20 to 40	301	173	102
	Total	2910	2163	1678
Improved, y_1	initial for 40 years	3228	2454	1945
	gradient 0 to 20	522	408	323
	gradient 20 to 40	552	318	187
	Total	4302	3180	2455
New road plus existing, y_2	initial for 40 years	4201	3194	2531
	gradient 0 to 20	801	627	496
	gradient 20 to 40	847	488	288
	Total	5849	4309	3315

*Based on unit taxes as shown in Table 7.4(b) on annual volume data in Appendix 3 1, and on use of Eq. 3.22

APPENDIX 3 10

PRESENT VALUE OF COSTS AND BENEFITS OVER 40-YEAR PERIOD (IN $1,000's)

Item	Low Cost Systems									High Cost Systems								
	4%			6%			8%			4%			6%			8%		
	y_0	y_1	y_2	y_0	y_1	y_2	y_0	y_1	y_2	y_0	y_1	y_2	y_0	y_1	y_2	y_0	y_1	y_2
I Net Present Value:																		
Discounted values: Highway construction costs	—	600	876	—	600	876	—	600	876	—	1,100	2,752	—	1,100	2,752	—	1,100	2,752
Discounted values: Net highway roadway costs	—	—	312	—	—	356	—	—	376	—	280	624	—	320	711	—	338	752
Discounted values: Highway maintenance costs	884	624	1,256	672	476	956	532	380	768	884	624	1,256	672	476	956	532	380	768
Discounted values: Highway user costs	76,660	54,778	80,374	56,703	41,816	59,181	43,813	32,122	45,381	76,660	54,778	80,374	56,703	41,816	59,181	43,813	32,122	45,381
Total costs	77,544	56,002	82,818	57,375	42,892	61,369	44,345	33,102	47,401	77,544	56,782	85,006	57,375	43,712	63,600	44,345	33,940	49,653
Discounted total benefits	79,570	59,080	86,223	58,866	44,996	63,490	45,491	34,577	48,696	79,570	59,080	86,223	58,866	44,996	63,490	45,491	34,577	48,696
Net Present Value	2,026	3,078	3,405	1,491	2,104	2,121	1,146	1,475	1,295	2,026	2,298	1,217	1,491	1,284	(-110)	1,146	637	(-957)

II. (r) Rate-of-Return:

Low Cost	y_0	$r_0 > 50\%$
	y_1	$r_1 \approx 25$
	y_2	$r_2 \approx 15$
High Cost	y_0	$r_0 > 50\%$
	y_1	$r_1 \approx 11.5$
	y_2	$r_2 \approx 5.8$ ← Rejected at 6% and 8%

(Projects having incremental rate-of-return relative to next lowest cost project that is acceptable) ≥ cost of capital at:

i = 4% Low	i = 4% High	i = 6% Low	i = 6% High	i = 8% Low	i = 8% High
y_1 yes	y_1 (yes)	y_1 yes	y_1 yes	y_1 (yes)	y_1 yes
y_0 no	y_0 no	y_0 no	y_0 (yes)	y_0 no	y_0 (yes)
y_2 (yes)	y_2 no	y_2 (yes)	y_2 —	y_2 no	y_2 —

Preferred alternatives by rate-of-return circled

III. Annual Cost (on an equivalent annual basis):

Low Cost Systems									High Cost Systems								
4%			6%			8%			4%			6%			8%		
y_0	y_1	y_2	y_0	y_1	y_2	y_0	y_1	y_2	y_0	y_1	y_2	y_0	y_1	y_2	y_0	y_1	y_2
3,917	2,829	4,184	3,813	2,851	4,079	3,719	2,776	3,975	3,917	2,869	4,294	3,813	2,905	4,227	3,719	2,846	4,164

IV Benefit Cost Ratio (using equivalent annual costs and benefits; highway maintenance costs regarded as costs):

	Low Cost Systems									High Cost Systems								
	4%			6%			8%			4%			6%			8%		
	y_0	y_1	y_2	y_0	y_1	y_2	y_0	y_1	y_2	y_0	y_1	y_2	y_0	y_1	y_2	y_0	y_1	y_2
Basic ratios	1 03	1 05	1.04	1 03	1.05	1 03	1.03	1 04	1 03	1 03	1 04	1 01	1 03	1 03	0 998	1 03	1 02	0 981
Incremental ratios	y_0/y_1 0 951		y_0/y_1 1 012	y_0/y_1 0 958		y_2/y_1 1.001	y_0/y_1 0.971		y_2/y_1 0 987	y_0/y_1 0 987		y_2/y_1 0 962	y_0/y_1 1 015		—	y_0/y_1 1 049		—
			(y_2)			(y_2)		(y_1)			(y_1)		(y_0)			(y_0)		

Discussion

Richard M. Soberman

ASSOCIATE PROFESSOR OF CIVIL ENGINEERING
UNIVERSITY OF TORONTO

This report really deals with two distinct issues each of which can almost be dealt with separately. On one hand, the authors exhaustively deal with the subject of the different techniques of project evaluation currently used by transportation engineers. The second issue and perhaps the primary one is a redefinition of many of the concepts which represent inputs to the project evaluation procedure which is finally selected. In particular, the authors have transformed some fairly rigid traditional concepts about what constitutes a "highway benefit" from the engineers' point of view into somewhat more strictly economic concepts.

The comparison of project evaluation techniques is extremely useful and does succinctly point out the advantage of using present value methods inasmuch as they obviate two of the major problems, namely, differences in facility life and differences in traffic volumes among alternative facilities being compared. However, what the report fails to do is satisfy this reader fully that the fairly complex definitional system of benefits which has been suggested is really going to do something that cannot be already done by a comparison of user and maintenance cost reductions with costs of construction in the traditional sense. The problem example, for example, does not really point out why using the authors' schema of benefits and costs gives different or better results than the traditional concepts (wherein benefits are considered to be savings in user costs). In view of the length of the report, it seems reasonable for purposes of this presentation to comment only in general on the authors' approach to each of the two major issues mentioned previously and to minimize specific comments to the extent possible.

Certainly the major interest focuses around the conceptual framework which the authors have formulated for the measurement of highway benefits and cost. This framework has been presented in terms of the economist's supply and demand functions wherein benefits are directly related to the demand schedule and costs to the supply function (price-volume curve). The main reasons for formulating these benefits and costs in terms of the new framework appear to be as follows:

1. The more usual manner in which highway benefits are measured, namely, as differences in user costs, cannot be effectively applied in cases where there are differences in traffic volumes using alternative facilities; and
2. This traditional method is not used on any widespread basis by other than water resources and highway engineering personnel.

The second argument does not appear to be a very weighty one. The types of projects which water resources and highway engineering personnel are called upon to evaluate are in many ways unique, inasmuch as it is often very difficult to trace the incidence of benefits and costs associated with each project. Thus there is no real reason why these professionals should not have a calculus all their own or at least specialized techniques which differ somewhat from the decision criteria which might be employed by private entrepreneurs (as for example, operators of a toll facility). The fact that in addition, these techniques may also be not very well understood by those who employ them (as the authors rightly point out) is just another reason why an attempt should be made to correct many misconceptions and misunderstandings.

The first point is, however, probably the more important one. Where there are differences in traffic volumes among alternative facilities, the traditional marginal benefit-cost approach does fall down, unless some attempt is made to impute by one means or another those benefits which accrue to the incremental volume using one facility (presumably the one providing the lower perceived price), and not the other. This imputed benefit might be denoted by one-half the difference in perceived price multiplied by the incremental volume. For a linear demand curve, this area turns out to be the same as the consumer surplus, for the incremental volume only. Determining the benefits in this manner however, involves making some assumptions about the shape of the demand schedule whereas one of the advantages of the method suggested by the authors is that no assumption must be made about the shape of the demand function.

On the other hand, there are many cases where differences in volumes using alternative facilities being compared are insignificant, simply because the nature of the improvement being considered is such as to provide no change in "perceived user price." Examples of such projects include improvements made to reduce maintenance costs or even a grade reduction project in which the apparent price which the user perceives for each alternative is small enough so as to have little or no effect on the volume of traffic using each facility. For this sort of example the sort of sub-optimization procedures commonly employed in which benefits are considered to be "cost savings" (as opposed to the authors' concept of "value"), should give correct answers in the sense that private entrepreneurs choosing among different machines or industrial processes would employ the same procedures.

With regard to the second major issue dealt with in this report, namely, the comparison of alternative methods of project evaluation, the authors present a fairly convincing case for the use of present worth methods of analysis over all other methods. This case is predicated on the following arguments:

1. Discounting future benefits over the life of the facility obviates the need to select any equivalent annual volume where traffic volumes are expected to increase over time (the more usual case), and
2. The problem of comparing facilities of different useful lives is circumvented without the need to make assumptions about the stream of benefits and costs accruing after the completion of the shortest project life in the analysis.

The first argument is a sensible one. Except in the very rare case where traffic volumes can be expected to increase uniformly over time the equivalent annual volume to be used in an economic evaluation can be obtained only by determining the present discounted value of the future stream of volumes and then multiplying this value by the equivalence factor, i.e., the capital recovery factor. Since the present discounted value must be determined before the equivalent annual volume can be determined it seems reasonable simply to work with the present discounted value in the first place.

The second argument is not nearly as clear. While it is true that if the present worth method is not used and two projects do differ with respect to their economic lives that some assumption must be made about reinvestment rates for the shorter lived project, it is not clear that the assumption which is made is an extremely critical one. For example, in one of the sample calculations two projects are presented each of which requires the same capital outlay but differs with respect to service life. The facility having a 30-year service life yields a net present value of approximately $54,000 and a rate-of-return of 6.5 percent whereas the project having a service life of 10 years yields a net present value of only $47,000 and a rate-of-return of 7.0 percent. The authors conclude that on the basis of net present values the longer lived project should be selected since the present value is higher unless the reinvestment rate for the shorter lived project is at least 6.025 percent.

Having determined this reinvestment rate the decision as to whether or not it seems reasonable is no more difficult to make than the choice of the appropriate opportunity cost of capital. Thus although the present value method is computationally less difficult (since the rate-of-return method requires a trial and error computation), it is not clear that it necessarily provides the correct answer. Perhaps what this means is that one ought really to look at both the rate-of-return and the net present value. In many cases of course, both the present value and the rate-of-return for one project will be higher than for all others and in such cases the choice will be a relatively easy one to make.

Two other points are probably worth commenting upon. Throughout the paper the authors have indiscriminately substituted the word "system" for "facility." The supply-demand relationships that have been discussed appear to be more relevant for the case of predicting facility as opposed to system usage. It is reasonable to talk about the price of a "trip" on a particular facility but not on a system which may accommodate trips of varying length and which are therefore not homogeneous units of output.

The final point pertains to the authors' suggested decision rule for choosing among alternative projects—that from among a group of mutually exclusive projects, the one having highest net benefits is selected. The proper decision rule really depends on the presence of any budget constraints and/or what alternative uses for the capital are available to the agency making the expenditure. Assuming that a highway agency is choosing one project from each of several groups of projects and assuming there is some limit to the total amount of money to be spent, selecting a project which maximizes net benefits from one group of projects may leave so little in the budget as to preclude the selection of worthwhile projects from other groups of projects. Practically speaking, this means that one has to consider the various combinations of projects from independent groups before selecting one project from a particular group. One method of doing this would be to ration the available investment funds by selecting from each independent group that project returning the highest net benefits per dollar investment.

In conclusion it should be emphasized that these comments are by no means intended to detract from what this discussant considers to be an extremely worthwhile report. Discussion is almost automatically defined as picking out the weak points in the arguments which have been presented. In view of the length of the report, the number of comments which have been raised here is really quite insignificant. This is indicative of the fact that the authors have presented an extremely cogent, thorough, and well thought out treatment of the whole subject of economic analysis of highway improvements. Even if the methods and concepts presented are not readily adopted by highway engineering personnel engaged in economic analysis, there is little doubt that a thorough understanding of the arguments presented in this paper cannot help but lead to better understanding and use of the "standard" techniques of economic analysis employed by highway engineers.

Gerald Kraft

PRESIDENT
CHARLES RIVER ASSOCIATES, INC.
CAMBRIDGE, MASSACHUSETTS

Wohl and Martin have discussed the problem of economic comparison of mutually exclusive alternative investments. While it is useful and necessary for the design engineer to understand this case, he should be aware that the broader question of the selection of investment programs, that is, the selection of sets of projects that are neither mutually exclusive nor necessarily independent, is a problem more relevant to real life situations and introduces complexities far beyond those discussed here today. The authors tell us how, in the restricted case, to select the project that maximizes net benefits. Generally, the problem faced by the typical highway department is the selection of a project subject to some budget constraint. The best project may not be feasible. Although the methodology is discussed in the framework of public or government investment in highways it is, of course, applicable and necessary to other types of public investment. Furthermore, there is a growing emphasis by governments at all levels to justify all types of projects using economic analysis.

From the economist's viewpoint, government investments, or private for that matter, divert scarce resources. There is some obligation to assure that the diverted resources provide greater benefit in the subject investment than they would in alternative applications. In the private sector of the economy the test is explicit and decisive: will the investment yield a return greater than its cost? The test in the private sector is profit.

The evaluation of government projects is not quite so simple. The government may have objectives beyond those that can be measured in simple monetary terms. Furthermore, the government may acquire resources through other means than private industry; this is particularly so in the acquisition of land. Since the government sector does not operate under the same set of rules as does the private sector, we are immediately presented with a possible double standard for evaluating investments. The authors suggest the same standard ought to be applied to both. Certainly the question is not easily settled. One question that arises in the extreme, for example, is: if a project would be profitable for a private investor, why not leave it for the private sector? If we applied the test in this way then, by definition, application of the same standards in both the public and private sectors would result in no government investment at all, except possibly in those few activities where private investors would have difficulty collecting from users or have difficulty identifying the users such as the case in defense or in the operation of a lighthouse.

For one reason or another, as a nation we have decided that government should provide certain goods and services. Also, for other goods and services that we choose to have provided by the private sector, we have taken the position that private ownership must be regulated. In general, we may argue that with certain types of investment, government operation is desirable and provides greater benefits than if the investment were left solely in private control.

While I do not wish to dwell on this subject which is more suitable for debate in other forums, I do think it is necessary at least to recognize that the single standard adopted may not be indisputable. While I agree with the idea of a single standard, my personal inclinations are to apply the standard in a slightly different way.

I believe most economists today accept "willingness to pay" as the measure of benefit. They are not in agreement, however, in defining this quantity. Marglin takes the position that the entire consumers' surplus, the entire area under the demand curve to the left of the output, should be included.[105] While under certain special conditions it is possible to exact the entire consumers' surplus through perfectly discriminatory pricing, I would agree that it is difficult, if not impossible, to measure consumer surplus with our limited knowledge of the demand curve, particularly far beyond the range of our normal experience. Most importantly, however, the use of consumers' surplus for the measurement of the benefit of government investment leads to a double standard. Benefit measured by consumers' surplus for the public sector makes public and private investment incomparable.

At the other extreme in definitions of "willingness to pay" are the authors who use what people in fact pay as the measure. If I interpret this approach correctly, under certain conditions of demand we could simply increase the user charge and thereby increase the benefit of the project. I do not believe we want an evaluation system that will yield this result, characteristic of any benefit measure that is dependent on actual output or consumption of services. An alternative measure, and one which I would suggest more closely parallels the private decision is: what is the maximum profit that can be obtained from the investment using a single price? In this case we still can assume a single price system, but we can set arbitrary prices. The measure of maximum possible profit from the venture has the additional important advantage that it is an inherent characteristic of the demand and supply relationships, independent of the quantity of output actually consumed. We may even consider discriminatory pricing, but I believe this would deviate from general private sector practice.

I believe that the authors foreclosed arbitrary pricing for several reasons: In highway systems, services are priced through generally applied non-discriminatory and non-project oriented user charges. He does allow price to vary in the toll road case, but even here he restricts the toll to equal average cost.

A further important point in this regard is the question of whether the charge must be imposed to achieve the benefit. Although the test applied is willingness to pay, ranking projects on economic efficiency criteria does not require consideration of actual revenues.[106] Although money plays many roles in our economy, for purposes of determining the benefit of government investment, money charges may be regarded as used to redistribute the benefits, generally from users to owners. Money is not a benefit itself. It is because of the distinction between benefit and charges that differences between public and private sector investments make the single standard difficult to apply. Whereas the private investor is concerned with income redistribution between his customers and himself, the government sector, on the other hand, may have deliberate policies to redistribute income among various groups in society, presumably for some greater good for all, and, consequently, may not wish to impose the charges. As an example, in New York City recent proposals have been made to subsidize the subway system from revenues derived from bridge tolls.

Needless to say, the possibilities of redistribtuion complicate the engineer's problem. For this reason, I believe it is more convenient for purposes of analysis to ignore the actual charges made, and merely adopt the private standard of the profit-maximizing revenue. If this is greater than the cost, we know that, if it were desired, we could charge a price that would cover our costs.

Wohl and Martin have decided to present their demand curves in an unconventional way. The customary demand curve uses, as a price axis, only those prices which

---

[105] See Arthur Maass, et al, Design of Water-Resource Systems, Harvard University Press, 1962, Ch. 2 by Stephen A. Marglin.

[106] When the measure of benefit is dependent on the quantity consumed, it is difficult to avoid consideration of actual revenues, such as in Mr. Wohl's measure or the consumers' surplus measure. There may be some validity, also, in the assumption that externalities are highly correlated with the quantity of output consumed, and hence there may be merit in explicit consideration of output quantity.

sellers receive from buyers. By incorporating the charges for other items, the price axis does not reflect the price that would necessarily be received by the owning agency. Usually the other items influencing the traveler's tripmaking behavior would be incorporated by using additional dimensions, in which case the single price-quantity demand curve is simply a projection from a multidimensional surface where all the other items are held constant. Undoubtedly, the authors felt that the use of the multidimensional demand curve would overcomplicate the presentation. While I agree that it may do just that, I also believe that the argument is clearer, the evaluation more straightforward, and the explicit information gained more relevant when all the dimensions are presented. In fact, it may be desirable for certain cases to recognize explicitly that the demand for transportation is a derived demand. This can be accomplished by modeling its derivation as a function of its relationships to the demands for other goods and services. In dynamic situations where the environment and the goods and services to be provided by transportation are likely to change, the explicit recognition of the character of transportation demand may result in improved accuracy and understanding of our forecasts.

Even with the complication of multidimensionality, we can still draw an ordinary price-quantity demand curve, but it will now represent that demand behavior that would exist if travel time, discomfort, inconvenience, etc., were held constant. An improvement in highway service would be represented by a shift in this price-quantity relationship due to changes in these other items. If the new investment improved the system, we would expect that more people would use the facility at a given price or, alternatively, current users would be willing to pay more for the service. The improvement, in other words, changes the product consumed and is represented by a new demand curve.

The explicit recognition of each item influencing demand, as opposed to converting them all into money terms and aggregating, offers the engineer extremely useful information for design. Knowing the relationship between each individual item and demand, the engineer can concentrate on making those improvements having the greatest impact. We do not know, for example, in looking at a movement along one of the authors' demand curves whether the movement is due to a change in the price charged or to a change in one of his other perceived payments.

The most important reason, however, for using this more conventional demand curve is that we are also able to construct a conventional supply curve. If we are to look at the question of "benefit to whom" we must separate the behavior of the owners from that of the consumers (even though they may be the same individuals). When we look only at the price-charged-quantity demand relationship we can quickly establish the revenue that is actually recoupable and hence can establish "willingness to pay." Furthermore, we can directly portray the owner's supply function and can establish the cost of the facility at any traffic level and hence can measure "profit."

I should point out before leaving this subject that the explicit multidimensional demand curve does not preclude the type of demand curve used. Quite the contrary, the multidimensional curve is necessary in order to construct Wohl and Martin's curve properly.

For government investments, the demand-supply relationships may be totally inadequate for the evaluation of total system benefit. While the private sector may be able to consider certain effects of a new investment external and hence may ignore them, the government sector cannot. I disagree with the authors regarding the extent that the private investor, particularly with respect to roads, can ignore externalities; nevertheless, my disagreement is probably only a question of degree.

The major difficulty in incorporating secondary and external benefits is the relatively high danger of double counting. Some ask the question of whether there are any non-user benefits that are not translated somehow into user benefits. Certainly this is a valid question when we talk about freight carried on the highway. The improvement in road transport service may lead to economies of distribution which, under certain market assumptions, will ultimately translate into user benefits. On the other hand, should the government consider the effect of its construction of a new road on a parallel private facility? While I do not pretend to be able to provide a general answer to these questions, I do think they are sufficiently important to be seriously considered in an evaluation of a new investment.

Moreover, as the authors admit, there may be benefits that are not translatable into money terms, except perhaps implicitly after the fact. They, however, exclude these from their analysis. In effect, they are almost saying, "if we cannot measure it, it is sufficiently unimportant so that it may be excluded from our economic analysis." I do not believe they mean it. In some cases, the items of benefit that can be translated into money terms may be only a small fraction of the total benefit; of course, we cannot know it because by definition the excluded items are unmeasurable. The analysis would be incomplete, however, if at least some information were not given. I suggest that the analyst consider these factors and make a simple calculation. When he has completed the analysis of measurable economic benefit he can say that, on the basis of the economic study, project A is better than project B but that if project B is selected, the difference in values of the non-measurable, factors between projects A and B would be imputed to be worth at least the difference in the calculated economic values between A and B.

I would consider three areas of evaluation: (a) measurable user benefits, (b) measurable non-user benefits; and (c) non-measurable benefits. Within each area further sub-analysis may be required. For example, under user benefits we may require separate analyses of private auto, bus, and truck users. Within each group we may have both pluses and minuses; there is no logical reason why all gross benefit elements need be positive. In computing the benefit, we may wish, for example, to deduct certain non-user costs to reflect possible compensatory payments made by the beneficiaries of the system.

Several important problems arise in connection with the evaluation of investments overtime. The authors discuss four capital budgeting techniques: (a) the annual cost method, (b) the benefit-cost ratio method, (c) the rate-of-return method, and (d) the present value method.

Many others are discussed in the literature and are used in practice, but these are the principal ones and since the set includes the one I feel is correct, I will restrict my discussion to these four. I agree wholeheartedly with the reasons for rejecting the annual cost method. There are other reasons but those given are certainly sufficient.

If capital were available in sufficient quantity to finance all projects having a benefit-cost ratio greater than unity, then the technique may have some merit. This, of course, is not the case and the complexity and confusion required for its proper use seems to demand its rejection.

The benefit-cost ratio tells us nothing about the total level of benefit derived from the project. If the ratio is greater than unity, it only tells us that benefits exceed costs. As a consequence, it does not help us, in the absence of a great deal of manipulation, to rank projects for investment when available funds are limited. In fact it will often lead to incorrect answers.

As a practical matter, the benefit-cost ratio suffers from its dependence on definitions of benefits and costs; there is always the possibility of one analyst considering an item as a cost, for example, that another would consider as a negative benefit. Even though the difference between benefit and cost, the net benefit, would be identical for the two analysts, the benefit-cost ratios may be vastly different. I believe this reason is sufficiently devastating to reject the technique. In any event, the inputs to the calculation of the benefit-cost ratio are the same as that for the present value technique, but in the process of computing the ratio we lose the most important information—the total net benefit.

The rate-of-return method suffers from one of the same deficiencies as the benefit-cost ratio; it provides us with no information regarding the absolute level of net benefits. Furthermore, the ambiguity arising in its interpretation, and the absence of solutions in certain cases makes it extremely suspect. The method may yield no real solution, or several. The interpretation of these alternative solutions is not clear. Also important, of course, is the difficulty in computing the rate-of-return.

Finally, we come to the present value method. From the standpoint of mechanics, this method can never fail to yield an answer. Moreover, in the solution of the more general problem of selecting investment programs requiring complex programming procedures to handle the complicated real life budget constraints appropriately, the measure of benefit derived by present value techniques results in correct ranking of projects.[107] Most importantly in terms of our desire for a single standard for public and private investment, the measure of present value probably corresponds most closely with an intelligent private investor's criteria. It answers the problem of investing a given amount of money in such a way as to maximize the absolute level of net benefit. If the net present value is positive using an appropriate interest rate, for example, we know that the project will yield a positive return even after the lenders are paid off. Thus we know the "rate-of-return" is positive; we also know that the benefit-cost ratio exceeds unity. In fact, it is difficult to see why any other approaches have been seriously considered, let alone used.

The problem of comparing projects with different lives is, I believe, a fiction. For any capital budgeting problem the analyst must have a time horizon (the horizon may, in fact, be shorter than the longest lived project); he should not attempt to evade and cannot avoid making at least some assumption about what happens when a short lived project runs out. Explicit recognition and explicit assumptions are essential in making comparisons between projects; ignoring them, or leaving them in the analysis only implicitly, will lead to incorrect decisions. In this I concur with the statement of Ezra Solomon.

Before concluding, I would like to say a few words about appropriate interest charges. The authors' argument here is quite correct. The common use of government borrowing rates certainly results in distortion of the value of public investment. Government borrowing rates are low for many reasons. Very simply the low borrowing rates do not reflect the values the lender places on a given project but, rather often reflect the full faith and credit of a large government organization.

In addition, at the state and municipal level, bond borrowing rates are even lower than that for the Federal Government due to the advantageous tax position offered on their interest. The appropriate rate to use is that which corresponds to private borrowing for specific projects of comparable risk and duration. Because of the extremely long life of government investments in highways, it may even be appropriate, particularly where explicit recognition of the uncertainty is difficult, to use a rate somewhat higher than that for private investment where the investment lives are often shorter.

In summary, while I disagree with elements of the authors' approach, particularly with respect to the measurement of benefit, this correction coupled with the overall methodology is far superior to the prevalent engineering textbook techniques. I believe this methodology leads to conservative appraisals of project investments and if followed will lead to improved decisions. To conclude, Wohl and Martin implicitly make it clear that there must be more extensive communication between engineers and economists. More economists should leave their blue books for a while and spend some time with the engineers giving serious attention to green and red books.

---

[107] See H. Martin Weingartner, *Mathematical Programming and the Analysis of Capital Budgeting Problems*, Prentice-Hall, 1964.

Robley Winfrey

HIGHWAY RESEARCH ENGINEER
U.S. BUREAU OF PUBLIC ROADS

This report is good reading: good reading for those who understand and those who do not understand the subject; for engineers and for economists; for those who agree and those who disagree with the concepts, principles, and procedures presented; and good reading for those thinking they know the subject of engineering economy as applied to highway transportation, but who are open to having their foundation of knowledge shaken a bit. I put myself into all classes, except that of being an economist.

The report is too long, too complex, and too detailed for a discusser to touch on all points worthy of discussion. However, the subject treated by Wohl and Martin is deserving of the extensive presentation they give it.

General Comments

This report is a thought provoking, real analysis of the finer factors and procedures involved in an analysis of alternative transportation systems or highway projects on the basis of the economics involved, or, more specifically, the relative economy of mutually exclusive projects.

The approach is somewhat different than has been presented in engineering papers over the past few years on the engineering economy analysis of proposed public works. Frankly, I have found it necessary to reorient my own thinking on the subject in order to atune myself to the philosophy and approach set by these authors.

To begin with, their development of the price-volume curve and the demand curve as applied to transportation systems is an application worth studying. Although I agree with this worthwhile approach, I am concerned with their calling the price per trip times the volume of trips (that is, the unit cost of transportation per trip times the number of trips) a benefit. I find it confusing though I am not saying that it is incorrect. I have customarily considered the benefit to be the reduction in costs between two alternatives rather than the benefit being the actual costs themselves. Perhaps calling the total cost "the value received" would be less confusing.

One thing that the paper does bring out which has been often overlooked is that as the traffic volume increases over the future years it is likely that the unit price per trip or per vehicle-mile will increase. I have been aware of this and have endeavored to get analysts to recognize that the slowing down of traffic as the volume picks up in the future years is an indication that there is a reduction in the net benefits to be achieved by future traffic as compared to initial traffic. The reduction of average speed as a result of speed changes often, but not always, results in increased running cost in cents per mile and increased travel time. The future years definitely bring increasing costs of transportation per unit rather than maintaining the costs per unit of transportation as prevailed the day the facility was opened to traffic. For this reason traffic surveys are needed of the speed of traffic over the entire year.

The report is written entirely on the basis of economic justification of proposals. It does not consider the second purpose of economic analysis, that is, for the formulation of the engineering details of design. In the latter application there is often not a null or existing situation, but the entire analysis is between new proposals. Proposed formulation frequently follows after the analysis for economic justification, particularly so after management has approved the basic proposal. Few people realize it, but the Interstate Highway System now under construction is an example of this character. Congress in 1956 provided for the construction of the 41,000-mile Interstate System. Therefore, to compare the economy of proposed segments (or contract sections) of the Interstate System with the existing parallel routes is merely an academic exercise because such analysis is unnecessary. The only analysis to be made is between the proposed alternatives, principally of highway location, the details of curvature, the details of gradient, and the details of traffic control, which are the aspects of engineering formulation of the project. The approach and concept in this case is somewhat different than it is in analyzing for the economic justification of a proposal.

In the discussion on interest, or discount rate, it is emphasized that the cash flows in the far distant future have little present worth today, and, therefore, are relatively unimportant. This is an agreeable statement; but on the other hand, throughout the report emphasis is put upon the analysis period over the service life of the facility. In fact, in the example, the authors set the service life of the right-of-way as perpetual and the service life of all construction items as 40 years. This does not seem consistent with the statement relative to the effect of long periods of analysis.

The report would be improved if at the outset there was some discussion of the purpose of the analysis. To me the purpose of analyzing the relative economy of proposed highway facilities is wholly on the basis of (a) economic justification and (b) project formulation, both to furnish the ultimate decision-maker with some guides which may help him arrive at decisions. There are many factors other than the economics involved on which the decision will be made. But true, the decision-maker ought to know the relative cost and relative benefits of the several proposals and their relative position. But in economic analysis he needs to know, also, what is the probable overall payoff to be obtained from the proposed facilities.

The analyst or the engineer of design does not make the decision to build or not to build. He merely makes an analysis and furnishes the ultimate decision-maker or management with his results, facts, and discussions to serve as a guide or tool in the hands of the person or group, empowered with authority to make the final decision.

The Price-Volume Curve

Not being an economist, I will comment but lightly upon the discussions pertaining to Figures 1.1, 1.3(a), 1.3(b), 1.4, and similar ones. The concept of the price-volume curves and demand curves for highway travel is a good one, but unfortunately it may remain within economic theory for some years, rather than find its way into practice. This statement is particularly appropriate when it is realized that the price as defined by Wohl and Martin includes all factors of value—tangible, intangible, realized, unrealized, and perceived. The pricing from which to compute the cost per trip on the new facility and any increase or decrease in cost is uncertain. The traffic volume—immediate as well as over future years—is a mixture of vehicles which come from the following sources, each source having its own old price base: (a) the existing old facility replaced or remodeled, (b) nearly parallel or alternate routes, (c) other modes of transportation such as rail or air, (d) induced or generated trips not existing in any form before the new facility was constructed, and (e) normal growth from increased population and increased use of motor vehicles. The real net change in travel cost to the users of the new facility is, therefore, most difficult to compute because of these different components of the total traffic stream. But the authors are not concerned with the change in price as such; only the price (or value) which the users of the new facility pay or are willing to pay for all satisfactions they receive. This makes for most difficult pricing.

The demand curve and price-volume curves are good concepts, especially for business, where the supplier need not be concerned with anyone's price or sales volume other than his own. In highways, though, the application and realities of prices, and demands are far more complex.

The demand curve concept and the price-volume relationship are sound economics, especially when applied to commercial sales. When applied to transportation, such as highways, some of the soundness becomes less sound. There is no known way yet devised to establish the "sales price" which the road user would pay, nor the volume of trips to be taken at any specific unit price. Further, the purpose of public highways is not to create travel ("increase sales"), but to provide the highway service the public wants consistent with the highest economy in the use of the highway funds.

Comparison of Methods of Analysis

The authors compare four methods of analysis in Chapter 2, but, in my judgment, somewhat unfairly. I say unfairly, because each method does have merits. A reader, not informed on the subject, may be led to conclude that only the net present value method should be used at any time. Industry makes widespread use of the equivalent uniform annual cost and rate-of-return methods. All four methods are correct unto themselves and when used properly each will lead to identification of the better alternative. I use all four methods, my choice being made on the basis of the particular set of proposals being examined.

The authors have restricted their concept to solely that of determining which of two or more mutually exclusive alternatives gives the promise of the greater economy. In other words, their discussion is wholly toward economic justification to the exclusion of project formulation, or project design.

Both applications of the procedures of economic analysis are highly important. One method of analysis may be more adaptable to one objective than another. For instance, the selection of alternatives from materials of construction—flexible vs rigid pavement—or certain other factors of highway design which do not affect motor vehicle running cost cannot be analyzed by the benefit-cost ratio or rate-of-return methods. But the present worth of cash flows can be used.

I agree that the equivalent uniform cost method or its equal, the method of present worth of the cash flows, should not be used on mutually exclusive projects wherein the services to be gained are not substantially equal for all alternatives. Therefore, the equivalent uniform annual cost method is not applicable to the selection from a group of mutually exclusive alternatives having materially different future traffic volumes.

I agree also that the rate-of-return method will result in two different solutions under certain conditions of delayed cash flows as between outlays and incomes. Such cases, though, are rare, even in private industry, so, for day-by-day application this hazard is seldom encountered. It is unfair to discard the method because of this weakness.

Often, the rate-of-return solution has a real meaning to the decision-maker. Its answer is in a term (return on investment) that has real meaning to most decision-makers. I can picture an executive decision-maker upon being shown that the net present value of Proposal A is $170,200 and that of Proposal B is $186,800 asking this question, "Well, what rate-of-return is that net present value equal to?" And then his second question, "What rate-of-return will we earn on the additional capital cost of Proposal B over Proposal A?"[108]

The Case of Unequal Analysis Periods

It is noted that the examples, Proposals A, B, and C have service lives of 10, 30, and 10 years, respectively. Unless the same period of analysis is used for all alternatives, either actually or implied, the analysis may lead to the wrong choice. For instance, assume the mutually exclusive alternates in Table D.1, A, B, and C being those of the authors.

Alternative B is selected over A and C primarily because its annual return continues for 30 years at the 6.5 percent rate, while the returns from A and C are for only 10 years at a 7 percent rate. For the remaining 20 years the authors' solution assumed only a 6 percent return on the reinvestment of the returns from A and C. The authors' solution is correct as made. However, the decision-maker may be misled unless he fully accounts for the 30 years for B and the 10 years for A and C. If A, B, and C are in reality mutually exclusive proposals, management must take some position now toward plans at the end of 10 years if either A or C is chosen. Management must con-

[108] This same basic idea is expressed on p. 49 of The Capital Budgeting Decision by Harold Bierman, Jr., and Seymour Smidt, Macmillan Company, New York, 1966.

TABLE D.1

SAMPLE CALCULATIONS TO SHOW THE EFFECT ON THE NET PRESENT VALUE OF DIFFERENT ANALYSIS PERIODS AND OF THE REINVESTMENT RATE

Alternative No.	Investment at Time N = 0 ($)	Annual Returns ($)	Analysis Period (years)	Calculated Rate-of-Return (%)	Net Present Value at 6% for One Cycle	Net Present Value at 6% for 30 Years*
A	400,000	56,951	10	7.0	19,164	35,841
B	1,000,000	76,577	30	6.5	54,069	54,069
C	1,000,000	142,377	10	7.0	47,907	89,593
D	1,000,000	1,070,000	1	7.0	9,434	137,648
E	1,000,000	553,092	2	7.0	14,035	105,380
F	1,000,000	243,891	5	7.0	27,358	89,371
C	1,000,000	142,377	10	7.0	47,907	89,595
G	1,000,000	109,795	15	7.0	66,356	94,045
H	1,000,000	80,586	30	7.0	109,253	109,253

*On the assumption that the first cycle, exactly repeats itself to the end of 30 years.

sider whether the probability of reinvesting the return from A or C at a rate in excess of the 6 percent cost of capital is greater than the probability that B will continue to return at the rate of 6.5 percent for the 30 years.

The economic analysis presented to the decision-maker must present all alternatives on an equal basis with full acknowledgment of the facts, forecasts, and assumptions involved.

The last column in Table D.1 gives net present values of A to H proposals based on repeating cycles of all proposals of less than the 30-year analysis period for the full 30-year period. On this basis, C is the best choice over A and B. Proposal D based on a one-year cycle is preferred to all other alternatives up to and including 30 years.

It seems as logical to assume (or to forecast) that the return on alternative A ($400,000 investment, and 7.0 percent return) could be repeated for the second and third cycles as it does to forecast that the 6.5 percent return on alternate B would continue for the full 30 years. At least, the chances should be equal that the reinvestment of the return from alternative A over a 30-year period would be as attractive as the reinvestment of the return from alternative B over the same 30 years, plus the uncertainty of the return of B continually for 30 years at $76,577 each year.

The above discussion is to point out that the number of years used in the analysis is critical, especially for the net present value method. Comparable analysis periods are essential, if reliable results are to be obtained.

The following two quotations are pertinent to the use of unequal analysis periods:

> Direct comparison of two projects is impossible when they cover different time-periods. One or both must be renewed until both cover a common multiple of the original time-spans. But for this purpose, it is necessary to know whether or not renewals can be made on the same terms. In the absence of this information, some assumption about renewal must be made. To compare A and B on the basis of discounted present worth is to assume that these "Dis-equilibrium" opportunities can last no longer than the stated time-periods. At the close of the 5-year or 10-year period, competition (or some other unspecified factor) will have removed the opportunity for renewal at a better-than-market rate. On the other hand, to compare A and B on the basis of

their respective internal rates of return is to assume an opportunity for renewal on the same terms as before.[109]

* * *

. . . When mutually exclusive proposals are being compared, it is necessary to compute the rate on each alternative course of action up to the terminal date of the longer-lived alternative. This requires an explicit estimate of the yield to be derived from the cash flows generated by each of the alternatives being considered.[110]

It is significant that in the examples A, B, and C, the authors include in their "annual project earnings at end of each year" return of capital and return on capital. Expenses for operations and of sales are excluded, therefore, their net present value is the present worth of the annual project earnings less the present worth of the capital outlay. In other words the net present value is exactly the present value of the net operating profit, or of sales less all expenses including depreciation. This concept is important in understanding both the method and its application in the case study given in Chapter 3.

The Authors' Example

The authors' practical example (Chapter 3) does much to clarify some of the factors and procedures involved in the four methods of analysis. The authors correctly forecast all three alternatives, including the null option, to the same future date. Correcting the road user costs for the effects of speed and hourly volume changes is a good practice, most generally overlooked by others.

In an example of this kind, assumptions are necessary and need not detract from the effectiveness of the example solution. In this example, however, the assumptions of the user price-volume Eqs. 3.5, 3.6, and 3.7, point out the fundamental difficulty of practical application of the authors' method. We just do not yet know how to determine a price-demand curve for a specific highway improvement proposal. We can compute the motor vehicle running costs and travel time for specific situations, but we do not know how to price the total value the user may place on a specific route or facility.

The Authors' Results

The authors' procedure produces a startling solution, at least startling to me, for I am used to thinking in terms of the decrease (or increase) in motor vehicle running cost, accident costs, and the travel time factor. The following results are taken from the authors' table, Appendix 3.10, for only the low cost system and the 4 percent

---

[109] Romney Robinson, The Rate of Interest, Fisher's Rate of Return Over Costs and Keynes' Internal Rate of Return: Comment, p. 72. See: Ezra Solomon, The Management of Corporate Capital, The Free Press of Glencoe, Crowell-Collier Publishing Co., New York, 1961.

[110] Ezra Solomon, The Arithmetic of Capital-Budgeting Decisions, p. 74-79.

discount rate, since the high cost system and 6 and 8 percent rates follow the same pattern:

	Alternatives		
I. Net Present Value	Y_0	Y_1	Y_2
Discounted value:			
Highway construction costs	–	600	876
Net highway roadway costs (ROW)	–	–	312
Highway maintenance costs	884	624	1,256
User travel costs	76,660	54,778	80,374
Total costs	$77,544	$56,002	$82,818
Discounted total benefits	79,570	59,080	86,223
Net present value	$ 2,026	$ 3,078	$ 3,405
FROM Appendix 3.9:			
Discounted road user taxes	2,910	4,302	5,849
Subtracting the highway costs as given above	884	1,224	2,444
Net road user taxes	$ 2,026	$ 3,078	$ 3,405

In other words, the net present value is simply the road user taxes less the highway costs, each properly discounted over the 40-year period. The authors set their data to produce this result, but they do not so state.

Again, this net of road user taxes above the highway costs is, in effect, placing the highways on a "sales income" concept. Such concept would work against highway improvements to reduce motor fuel consumption on the basis that the more fuel consumed, the higher the tax (sales) income.

There is economy to the road user in some highway improvements which reduce motor vehicle running and accident costs and provide an acceptable rate-of-return on the investment, but which improvement project would not pay for itself through road user tax earnings.

The authors' analyses by the equivalent uniform annual cost method is correct. As stated, this method should be used for comparisons of alternatives only where the service (ADT) are substantially the same.

The computation of the benefit-cost ratios result in ratios that are questionably low. The ratios of 1.04 and 1.05 for Y_1 and Y_2 (low cost system) are not in agreement with the order of magnitude of the calculated rates-of-return of 25 and 15 percent, respectively. The authors' ratios are merely the ratios of total discounted benefits (including road user tax costs) to these same costs plus the highway costs.

My concept of the benefit-cost ratio method is that it is the ratio of net gain to the net costs required to produce that gain. In the authors' method the motor vehicle running costs are in both the numerator and denominator, and these road user costs being large, overshadow any net reduction in road user costs or even the net highway cost. Further, the benefit-cost ratio usually compares pairs, that is, the benefits and costs are measured as changes from one alternative as the base to a second alternative.

If the benefit-cost ratio method as now understood is to be compared with the authors' proposed method of computing the ratio or with the present value method, a more effective comparison would be had if one solution were made by the commonly accepted procedure.

In the normal application of the benefit-cost ratio method, many (but not all) analysts place the highway maintenance costs in the numerator. Generally, this process will reduce the calculated figure for the net road user benefits. But in so doing, I doubt that these maintenance costs can be viewed as benefits as was indicated. Maintenance costs are simply annual costs that are necessary to produce the road user net benefits, the same as are the motor vehicle running costs. Therefore, these costs are appropriately used in the numerator to find the net annual benefits.

The authors' calculated rates-of-return for each separate alternative is made possible by considering the road user tax as equivalent sales income generated. In the usual solution of the rate-of-return (and benefit-cost ratio method) pairs of alternatives are considered and the rate-of-return is based upon the decrease in road user costs made possible by improving the highway above the level of that of the base (or null) alternative.

Concluding Remarks

The reader needs to be aware that the example solution given arrives at its numerical results principally because of the way the authors priced highway service. Another analyst could use the price-volume concept and the net present worth method and arrive at different results. Their final answers are based upon the road user tax payments and not upon overall reductions in road user travel costs.

My general nonacceptance of the authors' basic concept and, particularly, of its application in terms of road user taxes may be based on personal prejudice or blindness. I hope I am willing to change and to advance. Before changing to their concepts and procedures, however, I need to have more assurance of the soundness of their concept, of the practicability of application, and of the correctness of their procedures. I accept and do use the net present value method, as such, but question its application in the authors' examples. I am hopeful that we can develop a sound application of the price-volume concept to analysis of transportation public works.

Closure

Martin Wohl and Brian V. Martin

Judging from the discussions by Professors Soberman and Winfrey, we failed to make a number of important matters clear. In these closing remarks we will first endeavor to clarify some of the more crucial and general issues, and then attempt to answer some of the specific remarks of discussants.

First, as noted in the text the highway engineer or engineering economist often if not usually defines "benefit" to be the difference between the user travel costs before improvement and those after improvement; as noted in Table 1.2, this definition of highway benefit corresponds to our term "change in total perceived user net benefit," and is equal to the change in user consumer surplus that would occur with an improvement. Such a limited definition of highway benefit would only permit analysis of increments of investment over the lowest cost alternative considered and would not permit one to analyze the overall feasibility of projects. It must be emphasized that existing facilities can always be abandoned (particularly if economic losses are high) and that where only new facilities are being examined the lowest cost alternative is not necessarily better than doing nothing. This is the primary reason why we adopted the economist's concepts of cost and benefit in preference to those of the engineer; as a consequence, using the definitions we have outlined, one can analyze both the overall and incremental benefits and costs of projects. Thus, both questions of importance—Why do it at all? and Why do it this way?—can be answered. Also, let us point out that the highway engineer uses benefit more in the sense of profit (that is, gains minus losses) while the economist defines and uses benefit in the sense of total gain or value received from goods or services (and not net of costs).

Second, it is important to note that the procedures and definitions outlined in our report can be applied both to those instances where consumer surplus is excluded (as we have recommended) and to those where it is included. In these two cases, the appropriate measures of total and incremental benefit would be as given in Table C.1; in examining these measures it is important to remind the reader that they represent the benefits or increment in benefit before deduction of user travel costs (i.e., they are not net benefits in the sense often used by highway engineers).

Third, the various project analysis methods provide different measures of indicating the profitability of alternative projects or designs. Our problem is simply to determine which is the most appropriate method to be used for determining the net profit or net benefit of projects, all things considered. Briefly, our problem is to determine which project will maximize profit or the difference between discounted benefits and costs; or, alternatively, which project will accumulate maximum profits at the end of n years.

Neither businessmen nor governments (which merely act as agents for society) are interested in the profit per dollar of outlay or any other fictitious ratio; rather, both are interested in gross accumulated profit (viewed either in terms of its present worth or as accumulated by the n th year).

Sections 2.6 and 2.7 illustrate many of the difficulties of most methods and emphasize the errors which can result if certain specific assumptions are not made and accounted for. Particularly, the analyst is cautioned with respect to his use of the internal rate-of-return method; considering the common failure of the analyst to properly account for reinvestment earning situations and to compare the benefit and cost streams for equal time periods, our recommendation (and that of most economists, including

TABLE C.1

COMPARATIVE MEASURES OF TOTAL PROJECT BENEFIT AND INCREMENTS OF TOTAL BENEFIT

Total Project Benefit for:	Measures of Total or Incremental Benefit when: Consumer Surplus is Included	Consumer Surplus is Excluded
Project A	$(p_A)(V_A) + \Delta$ ACD	$(p_A)(V_A)$
Project B	$(p_B)(V_B) + \Delta$ BCE	$(p_B)(V_B)$
Increment or change in total benefit, comparing Project B to Project A	$\frac{1}{2}(V_B - V_A)(p_B + p_A)$	$(p_B)(V_B) - (p_A)(V_A)$

Mr. Kraft, a discussant) is to reject the rate-of-return method in favor of the net present value method (one which avoids these difficulties almost entirely and which is computationally much simpler).

To further highlight the difficulties which can and usually will result from using the rate-of-return method (because the analyst is not specific about reinvestment opportunities), another example is included.[111] (This example was brought to our attention more recently by Professor Julius Margolis of Stanford University and even later found to be covered in the Bierman and Smidt text, The Capital Budgeting Decision.) Assume that two alternative projects or designs being considered both will require initial outlays of $100 (at year 0) and will each last two years (before renewal, replacement or abandonment); for convenience, assume that we have no information or analysis which permits knowledge of the circumstances following the end of the second year hence. The annual earnings during the first and second years of the two projects (which for convenience we will assume accrues at the end of the year in question) will be as given in Table C. 2. Also, the discounted rate-of-return and net present value figures for the two projects are included.

For these calculations, the cost of capital (i.e., opportunity cost of capital) was assumed to be 5 percent over the 2-year period. Thus, other investment or reinvestment opportunities in the present and over the 2-year period under analysis are assumed to provide earnings of 5 percent per annum.

Using the rate-of-return criterion, project Y would appear to be the best or most profitable but project X would be best if we used the net present value method. Why the ambiguity? And which is the better alternative?

If the cost of capital is 5 percent, and if no other statements or assumptions are made with respect to the reinvestment rate for future earnings, alternative X is clearly superior. To understand this, let us determine the amount of capital we would have on hand at the end of the second year. At year 0, assume that we have $100 in the bank (or reserve fund) which we withdraw in order to invest in alternative X or Y, given that our cost of capital is 5 percent (i.e., given that other types of investments which are available to us will pay an interest of 5 percent—no more, no less). Also, given no other information, we can only assume that in future years other investments will provide earnings of only 5 percent.

[111] This example has been incorporated in Section 2.7.

TABLE C.2

PROJECT ANALYSIS CALCULATIONS FOR PROJECTS X AND Y

Item	X	Y
Initial capital outlay (at year 0)	-$100.00	-$100.00
Annual earnings or benefits accruing at end of year 1	20.00	100.00
... at end of year 2	120.00	31.25
Discounted internal rate-of-return for 2-yr period	20%	25%
Net present values for 2-yr period	$27.89	$23.58
Cost of capital	5%	5%

In this instance, for X, we will have a total of $141.00 on hand at the end of the second year (since the $20 earned at the end of year 1 was reinvested for one year at 5 percent, thus providing a total of $21 by the end of year 2 plus the $120 annual earnings for the second year). For Y, we will have a total of only $136.25 at the end of year 2 (since the $100 earned at the end of year 1 was reinvested at 5 percent, thus providing $105 by the end of year 2 plus the $31.25 annual earnings for year 2). Consequently, if we had adopted the rate-of-return criterion as our decision-making rule, and invested in project Y, we would have ended up at the end of year 2 with less capital than would have been possible with project X. Or, to put the matter another way, to use the rate-of-return criterion would imply that the reinvestment earnings rate (for the first year earnings) was higher than 5 percent (e.g., in this instance, the reinvestment would have had to be almost 11 percent for alternative Y to be more preferable). But in the absence of information other than the cost of capital, there is no reason to believe that the reinvestment rate is different from the cost of capital. Furthermore, if the reinvestment rate were different from the cost of capital, then necessarily the cost of capital must be changed (to be equal to the reinvestment rate) and thus the net present value figures must be changed accordingly.

As noted in the text, the rate-of-return as normally calculated implicitly assumes that the reinvestment rate (over the project life) is equal to the calculated rate-of-return. In essence, then, to adopt the rate-of-return criterion would be to assume that the reinvestment rate for project X would be 20 percent and that for project Y would be 25 percent. (It would appear illogical to anticipate different reinvestment earning rates for mutually exclusive projects; thus on these grounds alone, the rate-of-return criterion has shortcomings.) Given these reinvestment rates, the total accumulated earnings at the end of year 2 would be $144 for project X and $156.25 for project Y. Discounting these total earnings figures at the cost of capital (or 5 percent), and subtracting out the initial capital outlay, the net present value totals would be $30.61 for project X and $41.72 for project Y. In this case, since the same reinvestment assumptions have been made for both alternatives, both criteria would select project Y as best.

However, it would seem more appropriate to re-calculate the rate-of-return while assuming that the reinvestment rate for both projects was equal and that it was equal to the cost of capital; that is, a "corrected" rate-of-return should be calculated while assuming that the reinvestment rate for both projects was 5 percent. In this instance, it would be necessary to determine the discount rate for which the total accumulated earnings (after reinvestment) when discounted would just equal the discounted capital outlays. Earlier we computed the total accumulated earnings (at the end of 2 years) for a reinvestment rate of 5 percent; they were $141.00 for project X and $136.25 for project Y. For this case, the corrected rate-of-return would be 18.74 percent for project X and 16.73 percent for project Y; the net present value figures would be as shown in Table 2.9 or Table C.2. Again, since the same reinvestment assumption was made for both criteria, an unambiguous result would be forthcoming and project X would be selected as the best.

Again, and in conclusion, since the engineer seldom makes the necessary additional calculations to insure that similar reinvestment rates are used, it would seem apparent that the simplest and most reliable manner to avoid ambiguous and often misleading decision-making conflicts would be to adopt the net present value method of economic analysis. The method is more straightforward than the rate-of-return method; reinvestment is handled in an explicit and simple fashion; and trial and error calculations are avoided. More importantly, an improper and ambiguous answer cannot occur.

Reply to Richard Soberman

Soberman properly notes that we failed to provide sufficient insight regarding the necessity for defining a totally new structure (or at least what seems to be so) for the economic analysis of alternative projects. As noted in the preceding general commentary, the overriding purpose was to permit a more complete analysis than is now possible with traditional engineering techniques and to enable the engineer to analyze the feasibility of overall projects as well as increments of investment. Further, it is to develop a procedure more in keeping with the economist's literature and thus to permit engineers to take better advantage of the economist's findings and capabilities.

Professor Soberman, like Professor Winfrey, remains somewhat skeptical of the wisdom of rejecting the rate-of-return method in place of the net present value technique. Hopefully, the additional example and the more substantial comments to be included in our reply to Professor Winfrey will do much to clarify this important issue. Perhaps it is useful to note that Gerald Kraft (the economist among our three discussants) concurred with our findings and recommendations on this matter, saying in part: "In fact, it is difficult to see why any other approaches [than the net present value method] have been seriously considered, let alone used."

Reply to Gerald Kraft

First, Mr. Kraft's discussion provides a useful supplement to our paper and enumerates a number of the more crucial aspects of economic efficiency and economic analysis. However, one should note that the bulk of his remarks deals with topics which are outside of the general area covered by us. For example, we did not cover matters of program budgeting, of economic efficiency, of pricing, of income transfers and of demand forecasting, but we restricted discussion more narrowly (and purposefully) to economic analysis of mutually exclusive alternatives (given the ability to forecast demand, the existing pricing policies, etc.). That the broader economic and social issues raised by Kraft are important is undeniable; but we do not feel they could also be discussed suitably in a report of this length.

Second, Mr. Kraft's discussion of benefit measurement[112] and of the pros and cons of excluding or including consumer surplus (in the benefit totals) is important, though inconclusive. And while we share many of his doubts and worries on this matter, more

[112] Kraft comments extensively on the "unconventional way" in which our demand curves are presented (and from which benefits are derived) and notes the advantages of following the more "customary" demand and supply curve constructs. First, our constructs do not appear to be so unconventional as Kraft would insist; they compare, for example, with those adopted by Mohring, Kuhn, Beckmann, Vickrey and Zettel in some of their applications to highway transportation situations. Second, while we fully appreciate the views of Kraft on the detailed development of multi-dimensioned demand relationships, we feel the subject is much too complex for adequate discussion herein. In short, we were willing to accept the commonly accepted highway transportation demand constructs (at present) and to develop the appropriate economic analysis methodology, given that structure.

than anything else our conservative position (and recommendation regarding the exclusion of consumer surplus) is reflected in his telling statement, which read as follows:

> "Most importantly, however, the use of consumers' surplus for the measurement of the benefit of government investment leads to a double standard. Benefit measured... [to include] consumers' surplus for the public sector makes public and private investment incomparable."

In closing, let us say that these somewhat oblique remarks in no way are intended to diminish the well-founded and relevant comments offered by Gerald Kraft; in fact, we feel they are too important to be ignored, but nevertheless should be regarded as valuable extensions to our introductory subject matter (and as ones which are "more suitable for debate in other forums").

Reply to Robley Winfrey

We are grateful for Professor Winfrey's painstaking evaluation, though we do not concur with all of his comments. Of some considerable importance, Winfrey has in a few pages touched on the most prominent and key features of economic analysis and has focused the discussion on the central issues. The reader would do well to study carefully his remarks (and hopefully this closure), and then to reexamine our textural material and its references.

Reply to General Comments. Winfrey first raises the fundamental issue of defining (user) benefit and of specifying the relationship between user benefit and user "price." Quite properly, he notes that we have re-defined the term "benefit" as it customarily is used by engineers and particularly highway engineering economists. By and large we have adopted the terminology of the economist.

The actual price (in time, effort and expense) which users do pay when they travel results from the interaction of supply and demand conditions and is roughly equal for all users during the same demand period; this price would be p_A in Figure C.1 for System A. While this price is a measure of the actual user cost (since the demand and supply curves intersect at that point), it also is a measure of the perceived user travel benefit (or user travel value) accruing to the tripmaker at the margin, that is, to the last tripmaker. To put the matter another way, travelers are getting value or benefit from their tripmaking which is at least as high as the trip price (in time, effort and expense); however, in virtually all cases everyone but the tripmaker at the margin

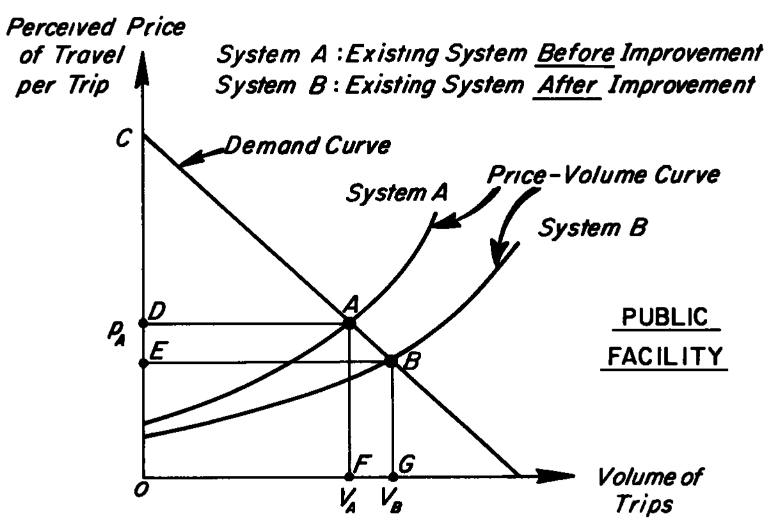

Figure C.1. Interaction of price-volume curves and demand curve.

will be willing to pay more (in time, effort or expense) than the price at the margin (i.e., more than p_A in Figure C.1) and thus receives more value or benefit from making the trip than p_A. Thus, common to the economics literature and practice, user travel benefit is defined as being equal to the amount which users would be willing to pay (whether or not they actually do pay it); thus the gross benefit is equal to the entire area under the demand curve and to the left of the equilibrium point or actual price (at the margin); for System A, the total user benefit would be equal to area AFOC, and for System B the gross user benefit would be equal to area BGOC.

Importantly, the unit user travel benefit and unit user travel cost (that is, cost in time, effort and expense—and assuming homogeneity) will be equal only at the margin, that is, at the equilibrium point. The additional travel benefit which users receive over and above what they do pay is what we call net benefit and is equal to the triangle ADC (for the entire group of V_A travelers and System A). In economic terms, the area ADC is called "consumers' surplus."

Whether or not the gross or total benefit including consumer surplus, or area ADC, should be included in the benefits category for economic analysis or justification studies is of course a matter of considerable debate and a matter of judgment; we have for the reasons explained in the text concluded that it is improper to include consumer surplus in the allowable benefit totals for carrying out the economic analysis. By contrast, most highway engineers do include consumer surplus in their benefit calculations, though unknowingly. Since we have excluded consumer surplus from the allowable benefit totals it should be evident that the total user travel cost will equal the total allowable user travel benefit (other than for the deletion of tolls or user tax payments).

Winfrey also comments: "The report is written entirely on the basis of economic justification of proposals. It does not consider the second purpose of economic analysis, that is, for the formulation of the engineering details of design. In the latter application there is often not a null or existing situation, but the entire analysis is between new proposals."

To begin, we believe that the outlined methods of analysis will properly handle the design situations noted by Winfrey, again from the standpoint of economic analysis. In the first place, there is always a null or existing situation, whether it is a poor road or trail or whether it is no road; as noted before, we feel that the engineer should not adopt the attitude that we do not have to examine the overall economic feasibility of a project but need consider only the increments of expenditure over the lowest cost new alternative. In the second place, if we find ourselves dealing with design details or alternatives which do not change the benefit side of the ledger, the methods of analysis we outlined are just as applicable. In short, for this latter case, we would need to examine only the changes in user and facility cost as we consider one design feature or another. (In other words, the net present value from design to design would change only to the extent that user or facility costs were changed.) Section 3.6 deals specifically with these kinds of situations. On the other hand, if changes in design affect perceived user costs, then these changes imply a shift in the supply (or user price-volume) curve and thus a shift in actual demand or volume usage of the facility; obviously, then, a change in user travel benefits can result and thus a full-scale analysis is required.

Also, Winfrey emphasizes that our "report is written entirely on the basis of economic justification of proposals" and that our procedures will sometimes involve the "academic exercise" of examining overall economic feasibility when policymakers or decision-makers have already decided that doing something is better than doing nothing. On the one hand, we must agree with Winfrey that it probably is "academic" to carry out the entire economic analysis in such instances since there is little likelihood of changing the policy decision, regardless of the fact that some proposal may be uneconomic. On the other hand, it is our feeling that the complete economic analysis should be conducted by the analysts and that the policymaker should be informed by the circumstances, either before or after the fact and regardless of whether the policy will or will not be changed. In fact, we know of no other way of improving the overall decision-making process and of guaranteeing that broad public decisions have properly accounted for the full economic consequences attendent with the policy.

Reply to the Price-Volume Curve. Winfrey notes that, "The concept of the price-volume curves and demand curves for highway travel is a good one, but unfortunately it may remain within economic theory for some years, rather than find its way into practice." Certainly, we must agree with Winfrey that the full practical development of these concepts lies many years ahead. However, we feel that it is first necessary to sketch out an appropriate framework and its usefulness, if we are to improve our analysis techniques. Moreover, we would insist that the travel demand models which were developed (principally by Gerald Kraft) for the Boston-Washington intercity passenger travel market are forerunners of more comprehensive and verifiable ones applicable to the highway problem with which we are concerned. Again, the first step is to recognize what is required.

Similarly, we would prefer to clarify Winfrey's following statement: "The demand curve concept and the price-volume relationship are sound economics, especially when applied to commercial sales. When applied to transportation, such as highways, some of the soundness becomes less sound. There is no known way yet devised to establish the 'sales price' which the road user would pay, nor the volume of trips to be taken at any specific unit price." First, it should be emphasized that there are known techniques to determine this information, though they are not highly developed. (Their improvement is simply a matter of time and sufficient research funds.) Second, the present-day non-availability of sufficiently reliable techniques for determining demand relationships in no way diminishes the soundness of the approach; rather it emphasizes the necessity for continued research in the direction we have suggested. Third, whether the highway engineer realizes it or not, every time he places a number on "user cost" (or on user cost reductions) then he has just guessed at or estimated what the sales price (or change in sales price) and resultant demand will be. Thus, in essence, we are simply suggesting that the engineer should be more aware of the actual interactions and demand relationships and should estimate the resulting conditions and prices (or, say, user costs) explicitly and directly rather than in some vague and implicit fashion.

We are not suggesting a change in what we are now doing, but merely a change in how we are doing it.

Reply to Comparison of Methods of Analysis. At the outset, Winfrey says that, "The authors compare four methods of analysis...but, in my judgment, somewhat unfairly. I say unfairly, because each method does have merits." Winfrey is correct in noting that "all four methods... when used properly will lead to identification of the better alternative," but he fails to point out that highway engineers or analysts seldom do properly use these methods; that is, seldom do they make the analyses for a common set of assumptions regarding analysis period or reinvestment rates. Thus, while we wholeheartedly agree with Winfrey on the techniques per se, we must re-emphasize that as a practical matter the net present value method is superior to the other economic analysis methods. In fact, in our judgment, it would be unfair to encourage engineers to use other techniques which if used in the traditional manner could give incorrect answers and which require more difficult and time consuming calculations.

Further, Winfrey says that, "I agree also that the rate-of-return method will result in two different solutions under certain conditions of delayed cash flows as between outlays and incomes. Such cases, though, are rare, even in private industry, so, for day-to-day application this hazard is seldom encountered. It is unfair to discard the method because of this weakness." First, let us point out that different solutions can result not only in cash flow situations, but in money or non-money, in tangible or intangible cost and benefit situations as well. Second, the fact that this "different solution" situation can occur (together with the computational difficulties involved in using the rate-of-return method properly) has been sufficient justification for virtually all professional economists and therefore for us as engineers to reject the rate-of-return method. Finally, we hardly comprehend what is so "unfair" about rejecting a method of analysis that not only can but on certain occasions does produce incorrect economic decisions.

Clearly, we would agree with Winfrey that "...the rate-of-return solution has a real meaning to the decision-maker," as noted in Section 3.6. However, we would go on to point out that it probably would not have so much meaning if the decision-maker knew it can and probably does (on occasion) give him incorrect economic decisions. (Also, the reader should not infer that Bierman and Smidt tend to prefer the rate-of-return method to the net present value method. Specifically, in their book they repeat over and over their preference for the net present value method. In the preface of their second edition they say, "The first edition of The Capital Budgeting Decision was written between 1957 and 1959 and was published in 1960. At that time we were convinced that the [net] present-value method was superior to other methods of making investment decisions, and we still believe this."[113] Later they add, "The [rate-of-return] method can also be used to make correct investment choices, provided the cost of money is the same in all future time periods. If properly used, the [rate-of-return] method will in fact lead to the same choices as the [net] present-value method. But the rules that must be followed if the [rate-of-return] method is to be used properly are quite complex.... For most of us, the [net] present-value method is simpler, safer, easier, and more direct. The remainder of this book will proceed in terms of this approach."[114])

Reply to the Case of Unequal Analysis Periods. First, we are in complete agreement with Professor Winfrey on the point of equal analysis periods and with his statement that, "Unless the same period of analysis is used for all alternatives, either actually or implied, the analysis may lead to the wrong choice." However, it must be emphasized that this does not mean that the service lives (or years until replacement) must be equal or that projects must be renewed or repeated until the end of the analysis period. (For example, if the analysis period is 30 years, then a 10-year service life project does not have to be renewed or replaced every 10 years.) Rather, it merely means that cost and earnings situation over the entire 30-year period must be fully accounted for, and in those situations when projects terminate prior to the end of the analysis period some account must be taken of the earnings situation after the initial project has terminated—whether it is renewed or not. It is also of vital importance to account for the reinvestment of earnings accrued during the project lives, as well.

The major thrust of our examples was to emphasize that typically most engineers and analysts do not properly take account of these reinvestment problems, but tend to use the data as provided in Tables 2. 7 and 2. 8 to make decisions among mutually exclusive alternatives.

The examples based on the data in Tables 2. 7 and 2. 8 (or projects A, B and C) dealt with the situation in which the projects were not renewed or replaced after one cycle. (Obviously, this is to assume that the projects if renewed or replaced would not produce cost and earning circumstances that are more favorable than outside opportunities which produce earnings of 6 percent. To put the matter another way, this is to suggest that the replacement cost and future earnings beyond the first cycle will change and will not be so favorable as in the first cycle, a not unlikely situation.) For this case, the net present values given in Tables 2. 7 and 2. 8 and in the "net present value at 6% for one cycle" column of Winfrey's Table D. 1 will not only represent the net present value during the project life but will also represent the net present value during the 30-year analysis period as well. (More specifically, from Winfrey's Table D. 1, the net present value figure of $19, 164 for project A is the net present value for both a 10- and 30-year analysis period if the project is not renewed.) Thus, the one-cycle cost and earnings for projects A, B and C are being compared over equal 30-year analysis periods so long as one uses the net present value figures as the basis of comparison. However, as we noted, the rate-of-return figures are incomparable, both among themselves and as compared to the net present value data. Furthermore, it is clear that for this case (of no renewal or replacement after the first cycle) project B is the most desirable, economically (among A, B and C). Again, this

---

[113] Harold Bierman and Seymour Smidt, The Capital Budgeting Decision, The Macmillan Company, New York, 1966, p. vii.

[114] Ibid., p. 48-49.

decision must be based on a comparison of net present value figures (as shown in Tables 2.7 and 2.8 or Table D.1) which are comparable and which are based on a 30-year analysis period for all projects; the rate-of-return figures cannot be used for this comparison since they result from an analysis of costs and earnings only during the project lives and, more importantly, since they assume different reinvestment situations, both among themselves and as compared to the net present value data. (Restudy of the example in Section 2.7 will be helpful.) For example, to use the rate-of-return criterion would be to assume implicitly not only that funds for projects A and C would be reinvested at 7 percent between years 10 and 30 but would also assume implicitly that earnings between years 1 and 10 would be reinvested at 7 percent. This would conflict with the stated reinvestment (of 6 percent) used to compute the net present value, and thus makes the two investment measures incomparable.

Winfrey seems to imply that all one needs to do in order to place the comparisons and projects on common ground is to renew or replace them for the full 30-year period and then to compute the new set of net present value figures which he has shown in the Table D.1 column headed "net present value at 6% for 30 years." This of course is not correct. First, it should be emphasized that this new set of figures is in no way comparable to our original set of net present values, since an entirely new set of cost and earnings situations has been assumed. In short, our problem dealt with no renewal and Winfrey's problem deals with that of continual renewal (up to 30 years); furthermore, he has added six more alternative projects to the list. Second, given the renewal case analyzed by Winfrey, it is obvious that project C would be preferred over A and B [115] whether one uses a rate-of-return or net present value criterion. Even so, we must re-emphasize that the two criteria are not comparable (even in this case of continual renewal over equal 30-year analysis periods) since the net present values are based on reinvestment of the earnings (from year 1 to year 30) at a rate of 6 percent while the internal rates-of-return are based on reinvestment of earnings at rates of 7, 6.5 and 7 percent, respectively, for projects A, B and C. In short, the criteria both indicated the best project (among A, B and C) merely by accident!

Third, if we view the circumstances for all 9 projects shown by Winfrey in Table D.1, all of which are continually renewed until year 30, it is clear that project D is the best investment situation if we use a net present value criterion.

But which project is to be selected if the internal rate-of-return criterion is to be used? Are projects C through H really the same[116], economically, if we use the rate-of-return criterion? And why do projects C through H show equal rates-of-return but different net present values if the measures are equally valid for making economic judgments? Winfrey does not indicate the answers to these important questions.[117]

At the outset, it is clear that the internal rate-of-return criterion would not indicate which project is preferable in this continual renewal, 30-year analysis period case. It is also clear that the internal rate-of-return and net present value figures for these 9 projects are not based on a common set of assumptions. For example, the rate-of-return for all projects but B is based on a reinvestment rate of 7 percent (for earnings from end of year 1 to end of year 30) while the rate-of-return for B is based on a reinvestment rate of 6.5 percent. Since the reinvestment rate is entirely independent of project earnings, it is not at all clear why project B reinvestment earnings should be expected to be different from those of other projects. Nor is it at all clear why the reinvestment rate should not be equal to the stated cost of capital of 6 percent. In any case, the rate-of-return method and net present value method should both be based on the same reinvestment rate assumptions (for all projects); that is, either the overall rate-of-return or the net present value figures should be recomputed (as detailed in Section 2.7).

[115] Project A would be rejected as being best since the rate-of-return on the incremental $600,000 investment (for higher cost projects) is at least as high as the cost of capital.

[116] See note 113.

[117] The quotes included by Winfrey from the writings of Robinson and Solomon are entirely correct on this score, but are couched in the usual economic jargon.

Perhaps the reader might be surprised to learn that if the net present value figures for projects C through H were re-computed while assuming that the reinvestment earnings rate was 7 instead of 6 percent, but with the same 6 percent discount rate, the new net present value figure for all 7 projects (C through H) would be equal and would be about $325, 290. On the other hand, if Winfrey had computed the overall rate-of-return for the various projects while using the same 6 percent reinvestment rate as used for computing the net present value figures, he would find that the "corrected" overall rates-of-return would rank the various projects in the same order as did the net present value figures!

The point of all this is simply that the engineer or analyst seldom does use a common set of reinvestment rate and analysis period assumptions, and thus can make incorrect investment decisions.

Just to point out how easily incorrect decisions can result from using the internal rate-of-return method (that is, by using data of the sort compiled by Winfrey in Table D. 1), let us reduce the annual returns for project D in Winfrey's table by only $10, 000 a year and note the results. The revised row of figures for project D would then become approximately as follows:

D	1,000,000	1,069,000	1	6.9	8,495	123,885

With these data for project D in place of those in Table D. 1 and using the internal rate-of-return criterion, we presume that internal rate-of-return advocates would now reject project D and say that projects C and E through H are all preferable to project D. However, such a conclusion would be incorrect since project D is still clearly the best investment among the 9 projects. Again, this emphasizes the weakness of the internal rate-of-return criterion, as normally calculated and used.

Finally, on the rate-of-return vs net present value argument, Hirshleifer, et al, have said:[118]

> . . .While it is true that the procedure of selection by marginal internal rate-of-return will often (perhaps usually) lead to the correct choice of projects, there are strictly correct methods of evaluation available which are no more difficult to apply and so should always be used instead. . . . Even aside from possible ambiguity in its determination, the internal rate as usually defined takes no account of the market terms on which funds needed in the project history can be obtained or of the market earning value of the cash proceeds thrown off by the project. To the extent that possible outside reinvestment opportunities for cash procceds, or the cost of funds in the outside market for required cash inputs, are considered, the analyst will be departing from the purely "internal" rate-of-return concept in the direction of correctly considering the relevant market alternatives.

Also, Bierman and Smidt summarize the situation as follows:[119]

> It is possible to use the rate-of-return method in such a way that it gives the same results as the net present-value method. In this sense the

---

[118] H. Hirshleifer, et al, Water Supply Economics, Technology and Policy, Univ. of Chicago Press, 1960, p. 171-172.

[119] H. Bierman and S. Smidt, The Capital Budgeting Decision, The Macmillan Company, 2nd Ed., 1966, p. 39.

two methods are identical, and if they are used correctly, either one is acceptable. However, if is the biggest two-letter word in the English language. It is easy to use the net present-value method correctly. It is much more difficult to use the rate-of-return method correctly—more difficult to describe what comparisons are appropriate for a given decision, and more difficult to carry out the required calculations. For both these reasons this book will consistently recommend the use of the net present-value method.

Reply to the Author's Results. Winfrey correctly notes that for our example problem, "...the net present value is simply the road user taxes less the highway costs, each properly discounted over the 40-year period." However, he continues, "The authors set their data to produce this result, but they do not so state."

As for the latter of these two comments, some clarification seems necessary.

Chapters 1 and 3 deal repeatedly with the principal issues of cost and benefit definition and of consumer surplus exclusion or inclusion (for the economic justification of investments). For our example problem, in which consumer surplus was excluded and in which we assumed that all changes in user travel costs (or prices) were reflected in the user price-volume curves, the result noted by Winfrey is a direct consequence of the two assumptions and not of "setting the data." The text repeatedly emphasizes the nature of these assumptions and is careful to note those instances when the assumptions were made merely for convenience of computation in the example problem. Specifically, in the example problem we assumed that travelers perceived all user costs and thus that changes in these costs which would stem from improvement would be reflected entirely in the price-volume curves for the different alternatives. For this assumption, and for the exclusion of consumer surplus, the net benefit would be the road user tax revenue. However, if we had chosen to assume that certain user costs and cost reductions would not be perceived by users or if we had chosen to include consumer surplus, then the net benefit totals would be different and would correspond to the conditions usually assumed by highway engineers. (Included in Subsection 1.3.3 and Sections 3.5 and 3.6 are the procedures to be followed for these alternative assumptions.) Again, the crucial matters involve the question of whether or not to include consumer surplus and the problem of developing appropriate price-volume curves (that is, of determining the extent to which users do perceive changes in travel costs).

These are precisely the issues which highway engineers to date have largely ignored or dealt with unknowingly, which are key to the problem of economic justification, and upon which we feel attention should be focused. Further, we are not unmindful of the fact that the highway community will generally be "startled" by the outcome since, historically, it has been willing to include consumer surplus (as a highway "benefit" and as a means of justifying improvements) without question or doubt. Again, while we would not argue that it is unquestionably wrong to include consumer surplus, we would insist that it is a matter of judgment, a matter to be openly discussed and a matter of considerable importance. (And, of course, we would recommend its exclusion for the many reasons outlined in Chapters 1 and 3.)

Later in this section, Winfrey argues that: "... this net of road user taxes above the highway costs, is, in effect, placing the highways on a 'sales income' concept. Such concept would work against any improvements to reduce motor fuel consumption, on the basis that the more fuel consumed, the higher the tax (sales) income." First, we would not regard the present tax rate as inviolable, and where facility expenditures can be made which will reduce motor fuel expenditures (or any other consumer value) at least as much, we would certainly be advocates of such improvements, but only to the extent that users or consumers are willing to pay for and do pay for such improvements. Obviously, this suggests a long-run adjustment between the size, extent and quality of our highway system and the associated tax rate. (Our conclusions on this matter admittedly involve questions of both economic efficiency and income distribution, the latter of which are ethical as much as economic. And, as noted earlier, we are less than sanguine about the existence and measurement of consumer surplus to the extent indicated by the ususal "draftsman's" demand curve.) Second, and contrary to Winfrey's conclusion, and given an inviolate tax rate (an assumption we do not necessarily endorse but will make for these purposes), our concept would not "... work against any improvements to reduce motor fuel consumption, on the basis that the more fuel consumed, the higher the tax (sales) income." Again, Professor Winfrey has overlooked the fact that facility improvements which will reduce fuel consumption usually will also lower the user price-volume curve, thus producing increases in user travel volume and possibly increases in net present value (depending on demand elasticity). Furthermore, and as pointed out in Section 3.6, in those cases where the price-volume relationships (or perceived user costs) are unchanged by highway improvements which do in fact reduce vehicle gas consumption or other operating costs, our methods and procedures do permit analysis of these economic consequences and, in turn, will lead to the economic justification of highway improvements for these purposes.

Finally, a few comments are appropriate regarding the computation of benefit-cost ratios and the rate-of-return. First, we have not dealt fully with all aspects of the benefit-cost ratio method as we feel it offers no technical superiorities over other analysis methods and has many deficiencies.[120]

Also, while our definition of the benefit-cost ratio method is not entirely apart from that of the engineer, we have relied on the methodological structure offered by the economist. As to Winfrey's objection to our including road user costs in the numerator and denominator, we would point that: (a) our benefit-cost ratios and our incremental ratios include all costs and all allowable benefits (i.e., excluding consumer surplus); and (b) the road user costs appear in both the numerator and denominator because the user price at the margin is equal to both the unit user cost and to the unit user benefit; however, if consumer surplus were to be included as a user benefit, then the user cost and user benefit items would not be equal. (See the remarks and formulation in Table 1.2 of our text for clarification of this point and for computation of the change in user benefit.) As for the necessity of computing both benefit-cost ratios and incremental ratios, we would argue that both sets of ratios should be computed, the first to determine the overall feasibility of the project and the second to determine the feasibility of increasingly higher cost projects (again, relying on the general methodology as outlined by economists). Also, while the principal decision facing the engineer is whether or not to commit resources (or capital) at the present time, projects should be ranked according to the total (discounted) costs which are thereby committed and not just the initial capital costs.[121] (The initial capital costs differ from the commitment of costs for maintenance, etc., only in terms of the time of their commitment.)

Finally, regarding the rate-of-return method and the accompanying calculations, the same sort of comments apply. The overall rate-of-return for projects must first be calculated and then the return on the increments of cost for successively higher cost projects must be computed, the first to determine the worthwhileness of the overall investment and the second to examine the worthwhileness of increments of investment. Also, it should be noted that the definition we used for rate-of-return (or incremental rate-of-return) is that it is the discount rate at which the discounted benefits (or incremental benefits) would just equal the discounted costs (or incremental costs); these definitions and practices stem directly from those of the economist.[122] Thus, we would argue that the rate-of-return method as explained in our text is fully consistent with the practice and principles of the economist.

Reply to Concluding Remarks. Winfrey says that, "The reader needs to be aware that the example solution given arrives at its numerical results principally because of

---

[120] For an excellent discussion of its technical deficiencies, see Hirshleifer, et al, op. cit., p. 137; also Kraft's discussion herein.

[121] See remarks of Solomon in Section 2.6.

[122] Hirshleifer, et al, op. cit., Chaps. 6 and 7.

the way the authors priced highway service. Another analyst could use the price-volume concept and the new present worth method and arrive at different results."

While we are not certain what Winfrey means in the first of these two sentences, we presume that he is referring to the fact that we include user travel benefit or value only to the extent that the user actually does pay for the service.[123] In this sense, he is certainly correct, and should another analyst prefer to include the consumer surplus or net benefit (i.e., the benefit to traveler over and above the amount he actually pays for) then different travel benefit totals and different net present values will almost always result.[124] Again, though, the crucial issue is not whether the totals would be different, but it is that of deciding whether or not to include the consumer surplus (and of measuring it, which is no mean task); this is a judgmental question and one deserving of far more attention than it has received in highway engineering economy circles. Similarly, should it be determined or assumed that users do not perceive all travel costs in the course of tripmaking (as noted in Section 3.6 of the text) then both the benefit and net present value totals can change, and thus other analysts making different assumptions can legitimately arrive at different results. Clearly, then, it is important for the analyst and highway engineer to be more deeply concerned with the manner and extent to which user costs are manifested.

Aside from the judgmental issues (to include problems associated with pricing policy, with income distribution, with the exclusion or inclusion of consumer surplus) and from the matters of determining suitable demand and equilibrium functions, there appears to be little (if any) virtue in hesitating to adopt a definitional framework and analysis methodology closely akin to that preferred by most professional economists, and as outlined herein. To do so may require some considerable re-learning by engineers but in all likelihood will result in better and more consistent investment decisions.

---

[123]Perhaps Winfrey is making reference to the broader subject of pricing policy in the sense used by the economist. In this case, the door would be opened to a wide range of issues, from the determination of differential costs to policy matters such as discriminatory vs uniform prices, etc. Again, we have presumed that Winfrey was not referring to these issues (which are important, but far beyond the scope here).

[124]The totals would not change for perfectly elastic demand situations.

THE NATIONAL ACADEMY OF SCIENCES is a private, honorary organization of more than 700 scientists and engineers elected on the basis of outstanding contributions to knowledge. Established by a Congressional Act of Incorporation signed by Abraham Lincoln on March 3, 1863, and supported by private and public funds, the Academy works to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance.

Under the terms of its Congressional charter, the Academy is also called upon to act as an official—yet independent—adviser to the Federal Government in any matter of science and technology. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency and its activities are not limited to those on behalf of the Government.

The NATIONAL ACADEMY OF ENGINEERING was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its Act of Incorporation, adopted Articles of Organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineering and share the responsibility of advising the Federal Government, upon request, on any subject of science or technology.

The NATIONAL RESEARCH COUNCIL was organized as an agency of the National Academy of Sciences in 1916, at the request of President Wilson, to enable the broad community of U.S. scientists and engineers to associate their efforts with the limited membership of the Academy in service to science and the nation. Its members, who receive their appointments from the President of the National Academy of Sciences, are drawn from academic, industrial and government organizations throughout the country. The National Research Council serves both Academies in the discharge of their responsibilities.

Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

The DIVISION OF ENGINEERING is one of the eight major Divisions into which the National Research Council is organized for the conduct of its work. Its membership includes representatives of the nation's leading technical societies as well as a number of members-at-large. Its Chairman is appointed by the Council of the Academy of Sciences upon nomination by the Council of the Academy of Engineering.

The HIGHWAY RESEARCH BOARD, an agency of the Division of Engineering, was established November 11, 1920, as a cooperative organization of the highway technologists of America operating under the auspices of the National Research Council and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the Board are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.

HIGHWAY
RESEARCH
BOARD

SPECIAL
REPORTS
91-96