NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 142

METHODS OF COST-EFFECTIVENESS ANALYSIS FOR HIGHWAY PROJECTS

TRANSPORTATION RESEARCH BOARD
National Research Council

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NATIONAL RESEARCH COUNCIL
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Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff Transportation Research Board

This synthesis will be of interest to planners, programmers, administrators, and others who need to make decisions on transportation-improvement projects. Information is presented on cost-effectiveness methods as a means of project selection.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

Many highway projects have multiple objectives and complex impacts that are difficult to measure and that may be in conflict with one another. This report of the Transportation Research Board discusses cost-effectiveness analysis as a method of assessing the worth of projects by providing information about costs, benefits, and impacts in a manner that facilitates broadly based decisions.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

METHODS OF COST-EFFECTIVENESS ANALYSIS FOR HIGHWAY PROJECTS

SUMMARY

When considering whether or not a project should be built, it is important to set priorities for highway projects that consider user and nonuser costs and benefits. One of the measures for prioritizing, particularly for determining the individual merit of a project or the most appropriate level of investment in a project, is a cost-effectiveness analysis.

In one way or another when setting project priorities, every state transportation or highway department does undertake at least some informal analysis of cost-effectiveness; however this analysis is not always on a formal, systematic basis.

What is the definition of "cost-effectiveness"? No simple dictionary type of definition has been accepted universally in the transportation field. Cost-effectiveness means achieving an objective for the least cost, or getting the best return for the money invested; for example, obtaining 80 percent of the objective for half the cost of 100 percent achievement. Because life-cycle costs should be considered, and funds might be invested either in one or two major projects, or several smaller projects system wide, cost-effectiveness analysis can become very complex.

Also, many objectives are nonquantifiable, so cost-effectiveness analysis relies as much on judgment and program objectives as it does on economic analysis.

This synthesis presents a brief overview of the traditional economic-analysis methods that have been used in the analysis of highway engineering alternatives. Then, because the earliest work in cost-effectiveness as a structured methodology was in the Defense Department, three basic criteria commonly used by the military are presented:

- Maximize net benefits
- Minimize the amount of resources required
- Maximize the level of service

The large amount of data obtained, with replies from more than 40 states, was assembled to meet two basic requirements:

- To compare the different methods of cost-effectiveness analysis highway personnel are using, and to determine which methods are most commonly used and which methods are most innovative.
- To develop a format that will assist highway personnel in selecting a method to set priorities and make decisions regarding a variety of highway programs or projects.

These criteria suggest placing the various methods reported into a series of categories:

1. Systems Analysis Packages. This category refers to multifaceted computer-based cost-effectiveness packages.

2. Sufficiency-Rating-Based Packages. Several states, already making use of sufficiency ratings based on the safety, service, and structural measures of their highways, have added elements of traffic service/congestion (V/C) and cost of improvements to develop a cost-effectiveness index.

3. Standard Benefit/Cost Analysis. Benefit/cost evaluations based directly on AASHTO's *Manual on User Benefit Analysis of Highway and Bus Transit Improvements* are in this category.

The following categories may be more akin to types of projects or applications than to categories but are included as an initial effort to cover the broad field of cost/benefit analysis.

4. Pavement Management Systems. Many states have developed these systems and use them to optimize the use of reconstruction, rehabilitation, and resurfacing funds for, say, a 10-year program.

5. Operations Cost-Effectiveness Measures. This category refers to the large number of traffic safety and operations improvements.

6. Construction Cost-Effectiveness Measures.

7. Maintenance Cost-Effectiveness Measures.

8. Private Investment Cost-Effectiveness Measures. Many examples are known of private investment in highway projects related to nearby private developments. These investments may be made to obtain a variance from zoning regulations, to meet highway department requirements, or simply to make the private development more accessible to motorists.

Examples in each of the categories are presented to show how each category could be very useful in the standard operating practices of every state DOT or highway department (in planning, project development, engineering design, construction, maintenance, etc.).

Although some states have developed and applied practical and very useful analysis methods to develop cost-effective solutions for highway and bridge problems, many states have not established systematic methods for setting priorities or level of project development. Reasons given include the need to collect and process large amounts of data, inadequate trained personnel or funding, lack of acceptance by decision makers, etc. However, most of the states surveyed believe that it would be worthwhile to devote much more time, attention, and money to cost-effectiveness analysis.

With transportation needs increasing much more rapidly than available funding, the authors strongly recommend follow-up work by AASHTO and TRB to establish in a more permanent manner the cost-effectiveness categories suggested and to make available the computer software used by several states, particularly the simplified procedures for prioritizing based on sufficiency ratings. All areas of transportation (planning, design, construction, maintenance) could benefit from the type of advancement most recently seen in pavement management systems.

CHAPTER ONE

INTRODUCTION

PURPOSE

It is always important to consider whether a project should be built and to set priorities for highway projects that consider user and nonuser costs and benefits. One of the measures for ranking, particularly for determining the individual merit of a project or the most appropriate level of investment in a project, is a cost-effectiveness analysis. The purpose of this synthesis is to describe the current state of the practice among state transportation agencies in using cost-effectiveness analyses.

In one way or another, every state transportation or highway department does set priorities for projects and undertakes at least some informal measure of cost-effectiveness. However, many highway projects have multiple objectives and complex impacts that are difficult to measure in common terms; sometimes those objectives can be in conflict with one another. In reaching project-level decisions, frequently there are problems in relating the costs of proposed improvements to the level of attainment of objectives and to the magnitude of impacts generated. Cost-effectiveness analysis is a method of assessing the "trade-offs" of a project by providing information about costs, benefits, and impacts in such a manner as to facilitate prudent, broadly based decisions. Thus, another purpose of this synthesis is to identify and discuss the methods of cost-effectiveness analysis that are practiced in reaching transportation-improvements decisions.

SCOPE

As described in Chapter Two, there are many economic-analysis techniques that have been developed and have been in use for many years in the highway-engineering profession. This synthesis focuses on only one of those techniques—cost-effectiveness analysis. However, to put cost-effectiveness into its proper perspective, the other commonly used economic-analysis techniques will also be summarized. For the latter, the reader is directed to other references for more details.

RESEARCH APPROACH

The primary source of information contained in this synthesis was a survey of the 50 state departments of transportation and highways in the United States. In addition, numerous personal contacts were made with individuals who are knowledgeable in the field, and an extensive literature search was undertaken. The results of that information gathering are reported in this synthesis.

REVIEW OF STATE DOT/HIGHWAY DEPARTMENT FUNCTIONS

It will be helpful at the introduction to this synthesis to review the functions of a state DOT or highway department to anticipate the areas in which cost-effectiveness analysis might prove helpful in decision making. Cost-effectiveness may be associated primarily with determining the level of development of specific projects. This review of all functions will illustrate that cost-effectiveness may also be used in planning, construction, and maintenance as well as in project development.

This review will deal broadly with the following functions: planning, design, construction, maintenance, and administration.

Planning

Planning will be considered in four parts:

1. Policy Planning, including Goals and Objectives and Systems Planning.
2. Financial Planning.
3. Programming.
4. Project Development.

Types of projects range from major capital projects to reconstruction and rehabilitation, safety, and major maintenance projects.

There have been attempts by state DOTs and the Federal Highway Administration (FHWA) to develop and use comprehensive, computer-based analysis packages to assist states in developing cost-effective programs that will best achieve state and local goals and objectives. Some of these analysis techniques include a cost-effectiveness element, as described in Chapter Four.

Financial planning, in its simplest terms, might be considered as determining how the total appropriation available for construction can be allocated to projects. The appropriation usually is allocated to various categories of projects, restricting the use of funds depending on the amounts that can be transferred from one category to another. In many states in recent years, the great majority of state-appropriated funds are used to match federal funds, which are distributed for projects in categories such as Interstate, Primary, Secondary, Urban, etc. However, with a growing proportion of state-funded projects, there is a need to develop better planning tools to develop cost-effective programs.

Programming has been described as matching available funds for a specific time period with projects ready for construction to achieve a highway department's objectives. If available funds are locked in to certain categories, it may be difficult to fund a series of projects considered to be cost-effective. For example, a new pavement management system may reveal many sections of highway in immediate need of repair. Delay may double or triple the cost of rehabilitation. However, if funding is not flexible, an overall cost-effective program may be unachievable.

Project development today is closely related to social, environmental, and economic concerns. "Feasibility studies" of the 1960s are now incorporated into environmental impact statements (EIS). There may be several levels of development considered (no build, minor build, major build). The minor build usually has less impact on the environment and creates less disruption during construction. If it achieves most of the project's objectives, it may be selected as the "least cost/most cost-effective" solution.

Design

Cost-effectiveness is desirable, and may be required, at the design stage. A directional interchange, though more costly, may eliminate weaving that makes a cloverleaf design inadequate. For the same reason (heavy weaving with today's traffic volumes) a semi-cloverleaf may work better at less cost than a full cloverleaf. Also, the FHWA requires that steel and concrete alternative designs be considered in bridge projects. Similarly, concrete pavements and bituminous asphalt pavements may both be considered. There are other design features for which cost-effective alternatives will be considered; for example, the use of guard rail versus clearing and gently grading a clear shoulder zone.

Construction

Some states encourage contractors to present alternative cost-effective construction methods other than those in the plans and specifications. This process, known as value engineering, can produce substantial savings, which may be split between the highway department and the contractor.

Maintenance

A new wave of maintenance practices oriented toward cost-effectiveness are being introduced in many highway departments because the cost of highway maintenance requires an increasing percentage of the total appropriation for highway departments.

These practices include computerized maintenance management systems and pavement management systems. They also include individual cost items such as recycling of existing pavements versus full-depth reconstruction; a larger crew versus a small crew with better equipment; in-house programs versus contracting out to private contractors; more expensive but more effective plow blades and sweeper brushes; etc. In determining the cost-effectiveness of projects, life-cycle costing includes maintenance over the life of the project. Often, high maintenance costs result in choosing a project with a higher initial capital cost and lower lifetime maintenance costs. Interest rates and the availability of capital funding will affect decisions, as well as cost-effectiveness.

Administration

Cost-effectiveness can also apply to administrative practices. Although not discussed in this synthesis (which is concerned more with project selection, development, and design), productivity studies, training, improved administrative equipment (computers, word processors, etc.), and other facets of administration can benefit from cost-effectiveness analysis.

CHAPTER TWO

OVERVIEW OF HIGHWAY ECONOMIC-ANALYSIS PROCEDURES

A major function of highway-engineering economic analysis is to provide a quantitative input to help in making decisions on investments, or to choose between alternative investments. Engineering economic studies address the question of whether a proposed improvement represents an attractive investment compared with other uses of available resources.

However, in addition to the need to quantitatively evaluate that question, in the public sector it is always necessary to evaluate issues that may not be easily quantified. This has given rise to the need for developing other measures for evaluating the relative merits of alternative investment strategies. One such method is to determine the "cost-effectiveness" of alternatives, in addition to determining their traditional economic benefits.

This chapter provides a brief introduction to the concept of cost-effectiveness analysis, within the context of the broader set of traditional economic-analysis methods that have been used in the analysis of highway engineering alternatives. Following a brief description of cost-effectiveness analysis is a description of the various economic-analysis methods.

COST-EFFECTIVENESS ANALYSIS (*1*)

Economic analysis can be divided into two general categories, as discussed above. The first is "cost-benefit analysis," which provides a quantitative assessment of the relative economic benefits of alternatives and provides a common measurement (dollars). The second category of economic analysis is "cost-effectiveness analysis," which deals with impacts that are not so easily quantified or for which there are no easily defined dollar values.

Measures of cost-effectiveness in terms of social and environmental impacts, the impacts on nonusers, and the like have been used in the highway engineering profession for some time. However, the concept of cost-effectiveness gained prominence through its use in the evaluation of military and space programs. For example, assume that some required task can be accomplished by alternative projects that differ in both cost and degree of performance. The effectiveness of each project is expressed in some standard unit, and the projects are then compared by a procedure analogous to that for a benefit-cost analysis (*2*).

In using this analysis, it is possible to obtain a money-based index that is helpful in comparing alternatives that are intended to reach the same general type of objective. Such an index might be computed as follows:

$$\text{Cost-Effective Index} = \frac{\text{Units That Measure Consequences}}{\text{Monetary Unit in \$}}$$

Various definitions of cost-effectiveness analysis are used in different fields and none has come to be universally accepted in transportation (*1*). All variations of the method have in common the use of nonmonetary effectiveness measures either to assess the relative impacts of all alternatives in the same terms or to hold constant the requirements that all alternatives must meet. The nonmonetary effectiveness measures are used in combination with cost values commonly, but not always, in the form of ratios. The more formal versions of cost-effectiveness analysis are designed to directly address the comparative overall assessment of transportation alternatives with each other.

Chapter Three discusses the concepts of cost-effectiveness in more detail.

There are several different economic-analysis methods that have been used as the basis for comparing alternatives:

1. The discounted cash-flow analysis methods are the most common, and include:
   - Present worth
   - Annualized
   - Rate-of-return
2. Benefit-cost ratio
3. Break-even analysis
4. Payback period
5. Capitalized cost

In addition to the above, several specialized methods have been developed, which are also briefly described in this chapter. They include:

1. Life-cycle cost analysis
2. Economic analysis of roadway occupancy for maintenance and rehabilitation (EAROMAR)

In using any of the above economic-analysis methods, the following important factors must be considered:

A. Inflation
B. Discount rates
C. Analysis period
D. Interest rates
E. Risks/uncertainties
F. Sensitivity analysis
G. Cost factors
   1. Design
   2. Construction
   3. Maintenance

4. Rehabilitation
5. User costs
6. Salvage value
7. Energy use

These factors will not be covered in this document. The reader should obtain other references for details. (See, for example, References *3–5*.)

The major source of information used to develop the summaries of traditional economic analysis is *NCHRP Synthesis 122: Life-Cycle Cost Analysis of Pavements* (*6*). That synthesis contains numerous technical references for further information. Other references used in the following sections of this chapter are noted accordingly.

The following sections briefly describe the economic-analysis methods listed above.

DISCOUNTED CASH-FLOW ANALYSIS (*6*)

Three methods that fit under the major grouping of discounted cash-flow analysis are discussed below. These three methods are the present-worth method, the annualized method, and the rate-of-return method. The first two have been the primary economic methods used in life-cycle costing analyses. The rate-of-return method requires more effort and calculations to perform, which are the main deterrents to its general use.

Present-Worth Method (*6*)

The present-worth method is an economic method that involves the conversion of all of the present and future expenses to a base of today's cost. The present worth of some planned future expenditure is equivalent to the amount of money that would need to be invested now at a given compound interest rate for the original investment plus interest to equal the expected cost at the time it is needed. For example, an investment of 30 cents at 5 percent compound interest will equal one dollar in 25 years. All costs are predicted and they are then reduced to one single cost in the present. The totals of these present-worth costs are then compared and the lowest-cost alternative is chosen, providing all other things are equal.

Several key items of information are needed to determine the present worth of rehabilitation and maintenance. These factors include a cost definition; a discount rate, analysis period, or life; a methodology for determining salvage value; and the expected life for the various potential rehabilitation alternatives.

Annualized Method (*6*)

The annualized method is an economic procedure that requires converting all of the present and future expenditures to a uniform annual cost. This method is one of the most valuable tools used in an economic analysis. It reduces each alternative to a common base of a uniform annual cost. The quality of the input data is important to ensure accuracy in comparing alternative choices. The procedure requires predicting all of the expected costs, whether positive or negative, over the life of the system. The costs are divided into uniform annual costs through the use of an appropriate discount rate. The annualized method can be used to convert initial, recurring, and nonrecurring costs to a series of annual payments. Recurring costs, such as estimated uniform annual maintenance expenditures, are already expressed as annual costs. A given future expenditure, such as a pavement overlay, must first be converted to its present worth before its annualized cost can be calculated.

The annual cost for initial costs and nonrecurring costs that have been converted to present worth can be calculated by multiplying the initial cost or the present worth of costs by the appropriate uniform capital recovery factor.

If all other things are equal, then the alternative that yields the smallest total annual cost is the best selection.

Rate-of-Return Method (*6*)

The rate-of-return method consists of identifying the discount rate at which two different alternatives for an economic problem have annual costs or present worths that are equal. The first step involves determining if the project is worth doing at all. The rate of return for each proposed investment is compared with the solution that requires the least capital outlay. Those plans that fail to show a minimum attractive rate of return are discarded. The rates of return on the increase in investment between proposals having successively higher first costs are then calculated. Any of the proposals that do not show a minimum attractive return when compared with the next lower are discarded. The alternative with the highest first cost that provides more than the minimum attractive rate of return on both the total and incremental investments is considered to be the best alternative from an economic point of view.

For example, when considering alternatives such as asphalt and concrete, the rate-of-return method requires determining the discount rate at which the present worth of both alternatives are equal. This usually occurs when the discount rate as calculated is representative of the return on the added investment in the original cost as required for one of the investments relative to the other. One alternative may have a greater first cost than another yet have lower total costs excluding interest over the analysis period. The rate-of-return method makes it possible to calculate the rate of return that may be obtained from the alternative with the greater first cost. The rate-of-return method has the advantage of not requiring the use of a set discount rate. The main disadvantage to its use is that it necessitates the calculation of rates of return on a large number of projects and on alternatives within projects in order to make comparisons.

BENEFIT-COST RATIO METHOD (*6*)

The benefit-cost ratio is a comparison of the equivalent uniform annual benefit (or its present worth) with the equivalent uniform annual cost (or its present worth). An alternative that yields a benefit-cost ratio greater than one is economical and the alternative that produces the highest incremental benefit-cost ratio is considered the best choice. The primary purpose for a benefit/cost analysis is to determine if the benefits to the public in dollars are greater than the cost of the project that would provide those benefits.

BREAK-EVEN ANALYSIS (*6*)

The break-even analysis is a means whereby alternatives can be compared by maintaining control on certain factors while allowing one factor to change until a point of equality is achieved between the two alternatives. By changing the value of one of the factors in the analysis and keeping all of the other points of difference between the two alternative choices at constant levels, it is possible to determine the value for the factor that will result in the two alternatives being equal economically.

It is important in a break-even analysis that all factors are considered and priced at their proper levels.

PAYBACK PERIOD (*6*)

The payback period is defined as the time period necessary to accumulate savings in costs or profits that would equal the investment. Payback period can be calculated with or without the time value of money and it has been used as an index to evaluate investment proposals on the basis that the alternative having the shortest payback period is the preferred selection. This analysis procedure is more generally used in the early stages of design and for relatively short time periods.

CAPITALIZED COST (*6*)

The capitalized-cost method for comparing alternatives is the present-worth method with the analysis period assumed to be infinite. With high discount rates, this method yields results comparable to the present-worth method with an analysis period of 50 years or more. The capitalized-cost method is rarely used.

SOME SPECIALIZED METHODS FOR ECONOMIC ANALYSIS

A number of analysis methods have been developed that incorporate the above economic-analysis concepts to establish more specific highway analysis methodologies. Two of the more important methods, life-cycle cost analysis and EAROMAR, are summarized below. The references indicated should be consulted for more detail.

Life-Cycle Cost Analysis (*6*)

NCHRP Synthesis 122 provides a comprehensive assessment of the current state-of-the-practice for this analysis method (*6*). It defines life-cycle costing as "...an economic assessment considering all significant costs of ownership over the economic life, expressed in terms of discounted dollars."

In general, life-cycle costs include all costs anticipated over the life (or analysis period) of the facility. The analysis requires identifying and evaluating the economic consequences of various alternatives over time. There are several economic-analysis methods that can be used for comparing alternatives, but discounted cash-flow methods (present worth, annualized cost, and rate of return) are most often used. Benefit-cost ratio, break-even analysis, payback period, and capitalized-cost methods are used less often. Factors that will influence the analysis results include inflation, discount rate, and analysis period.

Some of the components of the economic analysis will be well known (e.g., current construction costs), but others will be highly uncertain (e.g., future maintenance activities, intervals, and costs). Methods of decision analysis are available to help in making estimates for items for which there is uncertainty. A sensitivity analysis can be performed to determine which variables have the most influence on the cost of an alternative.

Of 49 North American agencies responding to a survey for *Synthesis 122,* 22 agencies specifically stated that they use some method of life-cycle costing in selecting pavement alternatives. Another nine agencies that claim not to be using life-cycle costing do use present-worth or annualized-cost methods for selection; these are economic-analysis methods used in life-cycle costing. Cost elements most often used in analyses were construction, rehabilitation, and maintenance. Salvage value and user costs were used by several agencies and a few included user costs and energy. Pavement-management systems are not yet providing data useful to pavement selection but are expected to do so in the future.

NCHRP Synthesis 122 (*6*) should be referred to for more details.

EAROMAR (*7*)

Decisions among competing pavement investment and maintenance strategies must be based on economic analyses considering both the costs and impacts of each strategy. Such analyses are sensitive to several local factors, including initial pavement design and construction, traffic loads, climate, maintenance and rehabilitation policy, maintenance technology, and unit costs. Of particular importance here are maintenance and rehabilitation actions, whose effects on pavement performance have not been studied extensively or quantified in the past. EAROMAR has been developed by the FHWA to assist in undertaking such analyses.

The economic analyses performed by EAROMAR are based on simulations of highway performance and costs, encompassing both the structural (i.e., pavement-related) and the operational (i.e., speed- and flow-related) aspects of road use. Costs predicted comprise highway agency expenditures for route or pavement reconstruction, pavement overlays, and pavement maintenance, and user costs of vehicle operation, travel time, and accidents, all discounted through an analysis period.

Costs are calculated through successive seasons within years, accounting in each season for the collective influence of pavement structural and materials properties, imposed traffic loadings, environmental factors, maintenance policies, local practices on work scheduling, and prevailing unit costs of maintenance labor, equipment, and materials on pavement damage and corresponding maintenance, rehabilitation, or reconstruction requirements. By performing the analysis for several different pavement designs and maintenance policies, one may compare the total discounted costs of each strategy to identify the least-cost combination of initial investment, subsequent investment, and maintenance.

The analyst could also compute changes in total discounted costs resulting from increments or decrements in numbers of vehicles, thereby establishing a basis for cost-allocation studies. Or, one could review maintenance management options regarding technology to be employed, work scheduling, or resources consumed, to balance agency expenditures in the face of rising prices against the potential disruption to the traffic stream or exhaustion of scarce or expensive materials.

The major components of the EAROMAR simulation are described in detail in Reference 7.

CHAPTER THREE

COST-EFFECTIVENESS ANALYSIS

Cost-effectiveness analysis arose out of a recognition of two basic realities of overall evaluation: (a) the frequent difficulty of transforming all major impact measures into monetary terms in a credible manner and (b) the fact that important evaluation factors could often be stated in quantitative or definitive qualitative terms in other more meaningful measures than dollar costs.

Some of the most important original work in formalizing cost-effectiveness analysis as a structured methodology was in the Defense Department. Here the original emphasis was on evaluation of the least-cost alternatives for satisfying predetermined military "requirements." The requirements were usually highly specific objectives that could not be given dollar values but could be measured or defined in very precise terms, and that could be precisely fixed by given military missions (e.g., logistics missions, such as being able to move a given amount of people and equipment over a specified distance in a given amount of time).

There are three basic criteria that should be considered in selecting the optimum alternative. The first is the most general and universal:

Criterion #1: Maximize net benefits (i.e., the amount that benefits exceed costs).

To achieve this, all economic-analysis methods that fall within this category seek to provide an explicit trade-off between monetary costs and all other important impacts.

Most of the traditional methods lead to the same criterion, if applied in compatible fashion. However, they require all evaluation factors to be translated into dollar terms—a requirement that is impractical to fully achieve in any decision situation involving major environmental and social impacts.

In order to evaluate the "effectiveness" of alternatives in nonmonetary terms, the concept of "cost-effectiveness" leads to a definition of the second basic criterion of overall evaluation, stated in terms that apply to transportation system evaluation:

Criterion #2: Minimize the amount of resources required to (a) achieve a given level of service and (b) meet other requirements demanded of the particular situation.

As long as definitive requirements can be established, this criterion provides a rigorous basis for uniquely determining the optimal alternative. However, in many situations "requirements" are not absolutes and are more correctly characterized as objectives with varying potential levels of satisfaction that depend on the nature of the alternatives and the amount of resources that are put into each.

At the other end of the spectrum of conditions that are faced in evaluation processes, the inputs available, rather than the outputs, might be rigidly determined. This situation leads to the definition of another criterion, which provides an equally rigorous basis for cost-effectiveness analysis, stated again in terms that apply to transportation system evaluation:

Criterion #3: Maximize the level of service, or other system performance measures, from a given level of investments and operating cost.

As with Criterion #2, as long as one component of the cost-effectiveness criterion (in this case the cost component) can be pre-established, while significant variations in the other component (in this case the outputs, level of service, or other performance measures) can occur among alternatives, then this criterion can be used to provide a rigorous basis for uniquely determining the optimal alternative.

Criterion #2 (minimize resources required to achieve specified objectives) is most applicable in situations where the following conditions occur:

- The level of funding is relatively undetermined or the real options cover a wide range of capital costs.
- A relatively high degree of consensus exists on the specific community objectives to be achieved (such as particular levels of highway and transit service or particular levels of modal split), so that these can be held approximately constant across alternatives.
- The benefits and cost of varying the levels of service and other community objectives are particularly difficult to evaluate in monetary terms.

These conditions often exist in evaluating transit options because of uncertainty of levels of funding, the great differences between capital costs of different options, and the difficulty of evaluating such factors as improved mobility for the transportation disadvantaged.

Criterion #3 (maximize the level of service, or other performance measures, from a given level of investment) may be more applicable when budgets are relatively fixed by earmarked taxes, such as in evaluating transit operating alternatives or in highway programming. It also will be more useful when the variable part of the criterion—e.g., the level of service—can be defined in terms that facilitate comparisons among alternatives (e.g., total travel time and costs to users, or total numbers of persons benefiting from a given higher level of service).

The use of either of the two cost-effectiveness criteria (Criterion #2 or Criterion #3) is more conducive to satisfying the second purpose of overall evaluation (comparison of alternatives) than the first purpose (justification of an investment). The application of either of these criteria does not result in a direct evaluation of whether the value of the benefits exceeds the added investment costs of any alternative. *Therefore, if cost-effectiveness is used as the basic method for the overall evaluation, it is desirable to also provide information relevant to Criterion #1, "maximize net benefits," as well as one or both of the cost-effectiveness criteria.*

Cost-effectiveness measures are useful in judging the justification for an investment, even if they do not provide explicit measures of return on investment. Cost-effectiveness measures should also be estimated for the "do nothing" alternative, to the extent applicable, in the same terms as for other alternatives. Figure 1 provides some possible measures of cost-effectiveness, many of which will aid in evaluating the justification for investment.

Cost-effectiveness criteria cannot, in general, be directly compared with any of the traditional methods of economic-efficiency analysis because, by definition, part of the cost-effectiveness criterion is stated in nonmonetary units. The most common general urban transportation performance measure that is used in corridor studies, level of service, can only be translated into monetary-benefit terms when the value of user benefits is estimated. In order to give decision-makers some appreciation for the justification for prospective investments, it is desirable to provide such conversions in addition to the basic cost-effectiveness measures that are to be emphasized.

In practice, the idealized extremes that lead to formal use of either of the two cost-effectiveness criteria do not exist in pure terms. Budgets are not rigidly established before system selection; nor are levels of service or other performance measures rigidly established before the costs of meeting these objectives are estimated.

In reality there are almost always trade-offs that can be made between the inputs and outputs of alternatives, so a unique "best" alternative cannot be determined from straightforward application of one of these two criteria. However, either of the two, or both, can provide a good framework for analyzing the trade-offs between costs and performance measures.

In practice, it is generally desirable to prepare estimates for several cost-effectiveness measures, rather than a single measure, because no single criterion satisfactorily summarizes the relative cost-effectiveness of quite different alternatives. Figure 1 lists some possible cost-effectiveness indexes that might be used for evaluating alternative transportation programs. Many or all of these could be used in a particular cost-effectiveness analysis. However, several other measures might be added, depending on local goals and objectives, or particular issues and conditions. Usually it is wise to limit the number of effectiveness factors to no more than five to seven in number.

Chapter Four provides some specific examples of various types of cost-effectiveness analyses that are typically undertaken by state DOTs.

TRANSIT

- o Increase in transit ridership per dollar of capital investment.
- o Increase in ridership per dollar of additional operating cost.
- o Total operating and capital cost per transit rider.
- o Total capital and operating cost per seat mile and per passenger mile served.
- o Decrease in average transit trip time (including wait time) per additional dollar of total additional cost.
- o Increase in transit accessibility of jobs (based on network impedances) per dollar of additional cost.
- o Increase in proportion of the population served at a given level of service (in terms of proximity of service and frequency) per dollar of additional cost.
- o Total transportation cost per passenger mile (auto and transit).

HIGHWAY

- o Increase in average vehicle speeds per dollar of capital investment.
- o Decrease in total vehicle delay time due to congestion per dollar of capital investment.
- o Increase in highway network accessibility to jobs per dollar of capital investment.
- o Decrease in accidents, injuries, and fatalities per dollar of capital investment.
- o Change in air pollution emissions per dollar of capital investment.
- o Total capital and operating cost per passenger mile served.

NOTE: This list includes only some of the more important overall summary measures used in cost-effectiveness analysis; it intentionally excludes the much longer list of evaluation measures to cover each category of impact or the incidence of impacts among different groups.

FIGURE 1 Some possible measures of cost-effectiveness for evaluating transportation alternatives (*1*).

CHAPTER FOUR

CATEGORIES OF COST-EFFECTIVENESS ANALYSIS

INTRODUCTION

In order to determine current practice of using cost-effectiveness analysis for highway projects, an inquiry was sent to all state DOTs and highway departments. Replies were received from more than 40 departments with a wide range of examples and comments on methodologies used.

In addition, a search was made of the TRIS (Transportation Research Information Service) database using the DIALOG Information Retrieval Service. The search included sources related to cost-effectiveness, cost benefit, and cost comparison for highways, bridges, culverts, pavements, construction, and maintenance, with cross-reference searches for these topics.

The information received in turn suggested other database sources, which were pursued in an effort to cover the full range of planning, programming, design, construction, and maintenance. Increasing activity in pavement management and highway safety was given special attention. Also, in recent years, private investment has been used to finance part or all of the cost of major highway improvements. In the past, private development usually followed the construction of new highways or highway improvements, particularly at interchanges on expressways. Today, developers are being much more aggressive and are paying for highway improvements as part of the overall investment in their project. In some cases, they are being forced into making the highway investment to meet strict environmental requirements. In any event, some developers are finding it cost-effective to accelerate highway projects rather than wait for them to be built by government.

CATEGORIES OF COST-EFFECTIVENESS

The large amount of data has been assembled to meet two basic requirements:

1. To compare the different methods of cost-effectiveness analysis highway personnel are using, and to determine which methods are most commonly used and which methods are most innovative.
2. To develop a format that will assist highway personnel in selecting a method to set priorities and make decisions regarding a variety of highway programs or projects.

These criteria suggest placing the various methods reported into a series of categories. The authors have selected a number of categories based on the information available at this time. This is appropriate because this synthesis represents current practice. In the long run, a broader framework of categories should be developed to fit all areas of highway activity. Such a framework would then both categorize existing methods and suggest areas in which new methods are needed.

As highway needs increase and funding does not keep pace, the need for more effective ranking methods will increase. It would be appropriate for a Transportation Research Board committee to take the findings of this initial synthesis on cost-effectiveness methods and develop a long-range format. In the interim, the following categories of cost-effectiveness plus a "standard benefit/cost analysis" method are presented to accomplish the objectives of this synthesis.

1. <u>Systems Analysis Packages.</u> This category refers to multifaceted computer-based cost-effectiveness packages. This category includes:

   HIAP Highway Investment Analysis Package—used in Idaho, New Mexico, Wisconsin

   HEEM Highway Economic Evaluation Program—has been used in California, Texas

   PPS Priority Programming System—used in Ontario and Texas

   PRIPRO Priority Planning Procedures—not used successfully to date

   PIAP Performance Investment Analysis Program—replaced by HPMS

   HPMS Highway Performance Monitoring System—has a cost-effectiveness index calculated by its Investment Performance Analysis Model.

   HUBAM Highway User Benefit Assessment Model—used by Transport Canada (*8*).

These packages have been tried, modified, used in part, discarded, etc. They require a significant amount of data collection and processing if they are to be of constant use. Some of these packages can be used in measuring what is the best timing for a program, or the change in benefits from delaying implementation.

2. <u>Sufficiency-Rating-Based Packages.</u> Several states, already making use of sufficiency ratings based on the safety, service, and structural measures of their highways, have added elements of traffic service/congestion (V/C) and cost of improvements to develop a cost-effectiveness index. Florida uses a package that is very similar to the intended use of PRIPRO (*9*, *10*).

3. <u>Standard Benefit/Cost Analysis.</u> Benefit/cost evaluations based directly on the American Association of State Highway and Transportation Officials' (AASHTO's) *Manual on User Benefit Analysis of Highway and Bus Transit Improvements* (*11*) are in this category. Bridge-replacement or -improvement projects are included, particularly in evaluating alternative routes if a bridge fails or is closed to traffic. It is assumed that many

states use this process. New Jersey, New Mexico, New York, Pennsylvania, and probably other states have computer-based programs. Idaho produces B/C evaluations through its HIAP program.

The following categories may not refer to the use of cost-effectiveness analysis for specific "highway projects"; some of them may be more akin to types of projects or applications than to cost-effectiveness categories but are included as an initial effort to cover the broad field of the use of cost-benefit analysis.

4. Pavement-Management Systems. Many states have developed these systems and use them to optimize the use of reconstruction, rehabilitation, and resurfacing funds for, say, a 10-year program. These systems are well documented (*12, 13*).

5. Operations Cost-Effectiveness Measures. This category refers to the large number of traffic-safety and operations improvements such as improved signal timing, flattening a dangerous curve, installing median islands or stop signs, and other operations/accident-reduction measures. These measures are usually very cost-effective, showing substantial return on very small investments.

6. Construction Cost-Effectiveness Measures. This category includes both construction methodologies and handling of traffic (traffic management) during construction (e.g., maintenance of equivalent lanes during construction vs. a shorter construction period with greater delays to motorists) (*14*).

7. Maintenance Cost-Effectiveness Measures. This category is used to refer to cost-effectiveness programs related to measures such as pothole filling, crack sealing, drainage improvements, size of crew vs. equipment to be purchased, assigning of personnel, etc. (*15*).

8. Private-Investment Cost-Effectiveness Measures. Many examples are known of private investment in highway projects related to nearby private developments. These investments may be made to obtain a variance from zoning regulations, to meet highway department requirements, to meet air-quality requirements, or simply to make the private development more accessible to motorists (*16*).

CHAPTER FIVE

SUMMARY OF STATE PRACTICE

INTRODUCTION

Chapter Four listed the categories of cost-effectiveness analysis. This chapter lists briefly which states are performing each type of analysis so that other interested states or organizations can contact them. Most of these states have had significant experience in the particular categories, have determined their usefulness, and have refined or simplified their procedures. In some cases, software has also been developed, making a particular procedure more attractive for experimentation in another state.

It can be noted from the following listing that several states have used cost-effectiveness analysis to accomplish or improve the following procedures:

1. ranking projects for a statewide, multi-year highway program
2. selecting corridors with the highest priority
3. selecting the most cost-effective alternative design of projects, including major interchanges and minor safety improvements
4. determining construction detours and traffic-management practices during construction
5. planning maintenance procedures from resurfacing to guardrail location to plantings to selection of plow blades
6. administrative operations and delivery of services.

In short, cost-effectiveness has been used in every phase of transportation department functioning: planning, programming, design, construction, and maintenance. However, it has not been used by most departments for most areas; it is hoped that this synthesis will increase the use of cost-effectiveness analysis among and within state DOTs.

SYSTEM ANALYSIS PACKAGES

A number of computer-based programs have been developed by FHWA or state highway departments, some in conjunction with universities or consultants, for project evaluation and priority. Because they require a mainframe computer to evaluate very complex equations, they have been referred to as complex packages. These packages include:

- Highway Investment Analysis Package (HIAP) was developed for FHWA by a consultant team. HIAP is a benefit/cost analysis package for evaluating highway improvements. The package has been applied in Idaho, New Mexico, Maryland, Michigan, Utah, and Wisconsin. Although HIAP can evaluate a broad range of improvements, it was specifically designed to evaluate *major* highway-capacity improvements and projects on new location.
- Priority Programming System (PPS) is a benefit/cost package developed for the Ontario Ministry of Transport and subsequently converted for U.S. use and applied in Maryland. Although PPS uses a slightly more comprehensive analysis procedure than HIAP, it is significantly more costly to run on the computer.
- Highway Economic Evaluation Model (HEEM) is a benefit/cost-type package (really a cost-effectiveness model) developed for the California Department of Transportation and subsequently used in Texas as well. HEEM has been used primarily to "down scope" major highway-capacity-increase projects to reflect tighter budgets.
- Performance Investment Analysis Program (PIAP) and Highway Performance Monitoring System (HPMS)—Both PIAP and HPMS were developed by FHWA to assist states in setting highway priorities, although HPMS is more suited to setting program priorities. Both of these systems use a highway inventory data file to produce sufficiency ratings and some cost-effectiveness measures for highway segments and improvement projects.
- HWYNEEDS is a methodology developed to estimate total highway improvement needs based on an assured set of standards. Although it has some usefulness for estimating long-range needs for major highway systems, it lacks the flexibility required to reflect the unique aspects of all systems.

Idaho reports using HIAP and HWYNEEDS on an annual basis to compare the results with the state's 10-year construction program. The project, based on both the systems analysis package data and various other ranking factors, compares favorably with a program that might be based only on the computer output.

Iowa has used HWYNEEDS for developing a 20-year plan.

SUFFICIENCY RATING SYSTEMS

Sufficiency ratings are the result of early efforts to assign point values to a variety of structural, safety, and service inventory items to calculate overall scores for comparing the relative value of proposed improvement projects. Many states continue to use these ratings, which deal more with improving the physical condition of highways rather than evaluating accident reduction, increase in capacity, or cost per mile. Of course, bringing highways to a consistent, higher level of design standard will reduce accidents and improve capacity.

Four states—Florida, Maine, Montana, and Texas—have reported methodologies that have added the factors of cost, length of project (therefore cost per mile), volume-capacity ratio (therefore average daily traffic), life expectancy, and other factors to their sufficiency rating equations. The result is a much more inclusive measure of effectiveness and project need than a sufficiency rating.

All states note that their "cost-effectiveness index is only one of several factors in the decision process." Yet, it is difficult to imagine making decisions without knowing the cost per mile or capacity increase possible, etc. Certainly, a "magic number" can sometimes hide as much as it reveals. It is necessary to give decision-makers the array of data and categories that made up a final index number, or they will not accept these numbers, made up by others, making their decisions for them. However, properly presented and used in the decision process, these index numbers can be a strong guideline.

STANDARD BENEFIT/COST ANALYSIS

Many states report using the AASHTO methodology to perform benefit/cost analysis. Although not truly a cost-effectiveness analysis, benefit/cost analysis is important. When combined with the judgment of experienced transportation professionals, it eliminates a lot of guesswork and eliminates ineffective alternatives.

States reporting the use of benefit/cost analysis include Connecticut, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, North Carolina, Ohio, Utah, Vermont, Virginia, West Virginia, and Wyoming.

Reporting computerized benefit/cost analysis were Idaho (produced by their HIAP program), New Jersey, New Mexico ("BENCOST" program), and Pennsylvania ("ECONS" program).

Texas reported a benefit/cost program that emphasizes cost per vehicle mile and delay.

PAVEMENT MANAGEMENT SYSTEMS

A large number of states have recently implemented, or are now implementing, a variety of pavement management systems to help identify the most cost-effective maintenance and resurfacing policy for each road segment. The most common categories of treatment are, in order of decreasing cost, reconstruction, rehabilitation, recycling, resurfacing, patch and seal, chip seal, crack sealing, etc. For each road segment, a life-cycle cost analysis of each treatment is calculated. A long-range program, say 10 years, is developed based on a given level of funding. A complex programming model is used to maximize the funding available, determining the amount of funding to go into each category of treatment and the segments to receive that treatment in each year of the 10-year program.

Arizona, California, Colorado, Florida, Kansas, Maine, New Hampshire, New York, Texas, Utah, Vermont, Virginia, Wisconsin, and other states have developed pavement management systems; Pennsylvania has developed its own "STAMPP" program.

It is expected that all states will quite rapidly adopt some form of pavement management system because of the cost-effectiveness of providing the lowest cost of treatment (over a life cycle) at the appropriate time before the road surface fails and improvement costs multiply.

OPERATIONS (TRAFFIC AND SAFETY) COST-EFFECTIVENESS MEASURES

The measures referred to in this category are usually less complex and of lower cost than the highway programs and projects in the previous categories. Many may be referred to as "traffic engineering" improvements involving traffic signs, signals, pavement markings, channelization, etc.

In most cases, the benefit-cost ratio is very high, reaching levels of 50 to 1 or higher. A 1982 study in 11 major cities throughout the United States reported a benefit-cost ratio of 30 to 1, considering fuel savings only, when traffic signal timings were optimized. Lane markings to provide channelization and turn lanes reduce accidents by 16 to 24 percent (*17*).

Although many states indicated benefit/cost was used extensively for safety improvements, several states report applications of cost-effectiveness in this category. For example, Iowa, Pennsylvania, and South Dakota use cost-effectiveness in determining the use of barrier/guide rail versus other measures, such as extended shoulders, flattening curves, etc.

Washington calculates a cost-effectiveness ratio for determining potential hazard locations, which make up about 60 percent of the hazard-elimination program. Projects are priority ranked based on this cost-effectiveness ratio, which is calculated as follows (*18*):

$$\text{Cost-Effectiveness Ratio} = \text{Cost/Relative Hazard Reduction}$$

$$= \frac{C_I + (Cm_A - Cm_B) + (P_{HA}\,C_{HA} - P_{HB}\,C_{HB})}{H_B - H_A}$$

Where

C_I	=	Annualized first cost of improvement
Cm_B	=	Annual cost of maintenance for existing obstacle
Cm_A	=	Annual cost of maintenance for improved obstacle
P_{HB}	=	Probability of striking existing obstacle
P_{HA}	=	Probability of striking improved obstacle
C_{HB}	=	Annual repair cost for obstacle before improvement
C_{HA}	=	Annual repair cost for improved obstacle
H_A	=	Hazard index after improvement
H_B	=	Hazard index before improvement

$$\text{Hazard Index } H = V[P\,(E)][P\,(C/E)][P(I/C)]$$

Where

V	=	Number of vehicles per year passing by obstacle
P (E)	=	Probability of vehicle encroachment on roadside

P (C/E) = Probability of a collision with obstacle given that an encroachment has occurred

P (I/C) = Probability of an injury accident (fatal or non-fatal) given that a collision occurs

Probably the most important use of operations cost-effectiveness measures occurs when several are used over a segment of roadway and eliminate or postpone the need for a much more costly improvement project. All highway engineers are familiar with such examples. Usually they are not planned that carefully based on potential cost-effectiveness. They result because of limited funding and an effort to make some form of improvement, which turns out to be adequate for current conditions.

Continued increases in traffic and limited funding can be expected to place emphasis on operations improvements. The Indiana Highway Commission authorized a study to develop a cost-effectiveness approach for evaluation of safety-improvement projects (*19*). The study, based on a group of safety projects conducted in recent years, found the cost-effectiveness approach is more appropriate than benefit/cost analysis because it can incorporate nonpriceable secondary effects with direct safety impacts of highway improvements. A modeling approach was developed to determine optimal budget allocation for selecting and programming different safety-improvement projects.

CONSTRUCTION COST-EFFECTIVENESS MEASURES

Several states encourage contractors to do "value engineering" on construction projects. Virginia accepts recommendations from contractors for changes in procedures, materials, etc. and splits the savings 50/50. Kentucky provides incentives for contractors to expedite projects.

Kansas, Kentucky, Illinois, and other states use cost-effectiveness as a guide to determine detours during construction. Both in the case of construction on new right-of-way where existing roads are affected, but particularly in the case of reconstruction, states are making substantially greater efforts than in the past to manage traffic during construction. Temporary roadways and bridges, construction after peak hours and at night, and many other measures are being used to meet the motoring public's demand for uninterrupted travel. Also, economic impacts of congested or detoured traffic become more significant as increasing traffic volumes attempt to use the same number of miles of highways. As the cost of managing traffic during construction escalates, greater emphasis on determining the cost-effectiveness of various measures can be expected.

MAINTENANCE COST-EFFECTIVENESS MEASURES

By 1982, nearly all states had either adopted or were developing some form of maintenance management system (MMS). Each system uses some form of electronic data-processing system to store data and produce reports. Most agencies include physical inventories in their MMS. This indicates the potential for measuring the cost-effectiveness of various maintenance procedures. Although not reported by any of the states, it is known that some states have experimented with the number of crews assigned to highway patching and pothole filling, the number of workers in each crew, the size of truck to be used, the type of material (hot or cold), etc., to determine the most cost-effective combinations.

Other states have taken a similar approach, perhaps not with cost-effectiveness in mind, to other maintenance operations such as catch basin cleaning, roadside spraying, pavement markings, snow plowing, etc.

California has developed cost-effectiveness approaches to highway planting restoration, drainage, and slope stabilization, and a study in Kansas determined that a more expensive plow blade is more cost-effective than a cheaper model.

CHAPTER SIX

SOME INNOVATIVE APPLICATIONS OF COST-EFFECTIVENESS ANALYSIS METHODS

INTRODUCTION

Cost-effectiveness does not necessarily produce a simple numerical rating. It may measure the number of tons of agricultural products brought from rural areas to market per million dollars of highway investment, thus determining corridors with highest priority.

In Georgia, economic analyses are used to narrow the selection of alternative corridors for segments of the economic development highway system. Currently, several routes are being studied for a proposed economic development highway to serve a 200-mile, east-west corridor linking three of the major urban centers and a number of rural counties where economic growth is lagging.

One of the principal factors being used in selecting alternatives for detailed location studies for this corridor is the economic development potential of each route. Essentially this factor represents a composite of several elements that measure accessibility and economic potential as expressed by recent trends in population, employment and income growth, industrial development, and quality-of-life values. A relative score based on a comparison of these elements affords a method of ranking alternatives for likely economic impacts.

Although not strictly a cost-effectiveness measure, more detailed economic studies on the location alternatives are expected to yield quantifiable economic results that can be used to weigh costs versus benefits. In this case, benefits would include not only traditional user benefits but regional economic benefits as well. (This assumes that highway improvements will result in new economic development.)

The feasibility studies and EIS for the Central Artery/Third Harbor Tunnel project in Boston produced some interesting efforts at new measures of cost-effectiveness. Predicting the length and duration of the queues presented the need for a new analysis technique, resulting in a paper by Lisco (*21*). The first analysis dealt with the length and duration of queues. Urban expressways are always congested to some extent. The relative degree of congestion with and without major improvements, such as the proposed $3 billion project, would be an indication of the cost-effectiveness of the project, particularly when compared with other alternatives.

A second approach to measuring congestion was determining the number of hours of the day the expressway system would be at level of service E or F, or volume-capacity ratio of 0.91 or greater. The EIS calculations predicted 14 hours of such condition without major improvements.

A third approach predicted the savings in person-hours by constructing the preferred alternative. Person-hours saved would be in proportion both to vehicle miles of travel and travel speeds.

A fourth approach determined how many of a selected number of central business district intersections, directly affected by expressway conditions, would be at level of service E or F.

A fifth approach involved accident reduction. This was determined both on a basis of improved design, 12 ft lanes with shoulders versus 11 ft lanes with no shoulders, and vehicle miles of travel or exposure to accidents. A 25 to 30 percent reduction was predicted. Of course, a reduction in accidents has obvious implications for time savings.

Following is a brief description of innovative analysis methods being used in various states, summarized according to the analysis categories described in Chapter Four.

CATEGORY 1. SYSTEMS ANALYSIS PACKAGES

These have been used in only a few states as a continuing tool. Perhaps as the country approaches the year 2000 and greater investments are made in developing new statewide transportation plans to meet the demands of the next century, interest in multifaceted complex packages will be renewed. The software for HIAP, HEEM, PPS, and other packages is now available. These packages are well documented (*9, 10*).

CATEGORY 2. SUFFICIENCY-RATING-BASED PACKAGES

At the present time, the less complex packages that produce a cost-effectiveness index seem more attractive for widespread use. Four such packages or programs, based on data regularly collected by states for sufficiency ratings or their equivalent, are presented, as developed in Florida (*22*), Maine (*23*), Montana (*24*), and Texas (*25*).

Florida

The Office of Transportation Priorities in Florida DOT has a unique ranking system for highway projects. After defining the projects, three terms are computed:

1. ER (Engineering Rating) = $\sqrt{\text{Operational Rating} \times \text{Structural Rating}}$.

The operational rating (OR) is a measure of the roadway's ability to adequately handle traffic. The structural rating (SR) is a measure of the roadway pavement structural condition.

OR = C * cos (V/C * 90) *cos (ALR * 90)
ALR = alignment ratio
SR = $\sqrt{RR \times DR}$
RR = ride rating (0-100)
DR = defect rating (0-100), cracking, rutting, patching, etc.

A more complete explanation of these formulas is available in Reference *18*.

2. Δ ER, which indicates what effect the proposed project will have for the scheduled year of construction.
3. CE (Cost-Effectiveness) = Δ ER × ADT × Length ÷ S
ADT = average daily traffic
S = cost (in $ millions)

The project having the lowest initial ER, highest Δ ER, and largest CE value would be the highest priority project. Priorities, therefore, are determined by combining these three terms, adjusting the resultant to a value of 0 to 100 to indicate the priority in respect to all other projects in the Project Record System (PRS). For example, a priority of 10 indicates that 10 percent of the projects in the PRS have higher priority than the subject project.

To determine the priority number, all of the projects in the work program are sequenced based on the ER, Δ ER, and the CE ratings. If the same rating is applied to more than one project, they will all receive the same sequence. At this point each project will have three sequence numbers; these are averaged to obtain an average sequence number. The average sequence numbers are then sequenced again and the final sequence number is divided by the total number of projects and multiplied by 100.

Maine

Maine DOT has a highway project prioritization system with weightings as follows:

HIGHWAY PROJECT PRIORITIZATION

Criterion	*Max Weighting (%)*
• Need	
- Transportation Plan	7
- Local Official	7
- DOT	12
- Community	4
• Cost-Effectiveness	
- Condition	
- Service Level, V/C	70
- Alignment	
- Accidents	
TOTAL	100

The formula for the cost-effectiveness calculation is the following:

$$CE = \frac{K \times ADT \times 365 \times L}{\text{Unit Cost}} (\Delta \text{ Condition} \times W1) + (\Delta \text{ V/C} \times W2) + (\Delta \text{ GEO.} \times W3) + (\text{Safety} \times W4)$$

K = normalizing factor
ADT = avg. daily traffic
L = est. project life
W1 = Weighting Factor – 50%
W2 = Weighting Factor – 10%
W3 = Weighting Factor – 10%
W4 = Weighting Factor – 30%

A more complete explanation of terms and intermediate calculations is available in Reference *23*.

Montana

The Montana Department of Highways uses a simplified "Cost-Effectiveness Index" (CEI) as one of several factors in final project selection process. It is used as a quick response technique rather than a slow, detailed analysis to rank primary highway construction, overlay, and major widening projects. The CEI is given by the formula:

$$\text{CEI\#} = \frac{S \times ADT \times Li}{\$/Le}$$

The following is a brief description of the parameters used to calculate the CEI.

S—The change in sufficiency of a highway segment caused by the project. The current sufficiency is found in "Montana Primary Highways Sufficiency Ratings." Proposed sufficiency is determined from the scope of work for reconstruction projects.

ADT—The current average daily traffic on that route.

Li—The lifetime of the project, which is the period over which benefits will occur. This converts annual benefits to total benefits. The lifetime of the improvement is the generally accepted engineering estimate. For instance, pavement life is considered 20 years, thin overlays and signals 10 years, and bridges 50 years. In practice the life span depends on many factors, but these estimates are sufficient for the relative ranking generated here.

$—The estimated construction cost of the project. The cost estimate is prepared by the field District, Preconstruction Bureau, or Project Analysis Bureau, based on an average cost per mile.

Le—The length of the project in miles. This converts all project estimates to cost per mile and allows consistent comparison of different kinds and lengths of project. The length of the project is specified in the project nomination.

Texas Priority Formula (*25*)

The Texas Department of Highways and Public Transportation studied three techniques for ranking highway construction projects: (a) sufficiency ratings, (b) priority formula based on sufficiency ratings, and (c) benefit/cost analysis, referred to as the Modified HEEM-II program. After using each of the three techniques to rank 1942 added-capacity projects, the Department selected the priority formula as the technique giving considerably more total benefits for a 10-year budget than the other two techniques.

There are two variations on this Priority Formula, one for added-capacity projects and one for upgrade-to-standards projects. The general equation for this Priority Formula is:

$$PF = \frac{(SR_E - SR_P)\left(1 + \frac{P}{100}\right)\left(\frac{2}{3}CADT + \frac{1}{3}FADT\right)}{(LTH)/CST}$$

where:

PF	= priority formula rating
SR_E	= sufficiency rating for existing facility
SR_P	= sufficiency rating for proposed facility
P	= sufficiency points for categories that do not change with improvement
CADT	= current annual average daily traffic
FADT	= forecasted (typically 20 years in the future) annual average daily traffic
LTH	= project length in miles
CST	= initial highway construction and right-of-way cost in thousands of dollars

The Priority Formula's selection of projects for the 10-year budget gives considerably more total user benefits (travel time, operating costs, accident costs) than does the sufficiency rating's ranking. For a 10-year expenditure program, the Priority Formula gives 114 percent more benefits than does random selection and 41 percent more benefits than does the sufficiency rating. This indicates that the Priority Formula, by (a) considering the change in the sufficiency rating, (b) by weighting the change in rating by vehicle miles of travel, and (c) by dividing effectiveness by project cost, transforms the sufficiency rating into a greatly improved rating method. This implies that the Texas sufficiency rating schedule does a good job of measuring the factors that affect benefits, but that the schedule must be used properly in a Priority Formula to become a good ranking technique.

The benefit/cost analysis is superior to both the sufficiency rating and the Priority Formula in maximizing motorist benefits. For the 10-year construction program, the benefit/cost analysis gives 62 percent more benefits than the sufficiency rating and 15 percent more benefits than the Priority Formula. This represents an increase in benefits of $22 billion relative to the sufficiency rating and $7 billion relative to the Priority Formula.

Because some version of sufficiency ratings is used to rank construction projects in most states, it is concluded that a large increase in benefits would result from using a priority formula or benefit/cost analysis.

CATEGORY 3. STANDARD BENEFIT/COST ANALYSIS

This category is not a cost-effectiveness tool. However, benefit/cost analysis is so fundamental to the operations of any highway department and in such widespread use it has been included in the synthesis. To be an effective tool and to lead an agency to the use of cost-effectiveness, computerization of the procedures seems most logical. Although several states noted they had software programs for benefit/cost analysis, many may not and it would be desirable for several states to share their experience and make a basic program available to all states.

CATEGORY 4. PAVEMENT MANAGEMENT SYSTEMS

It was not possible in this synthesis to single out the most innovative pavement management systems. However, conferences dedicated to this topic and the sharing of knowledge are proliferating to the point at which, in a few years, it can be expected that every state will have a 5- to 10-year program that optimizes the use of available funding.

CATEGORY 5. OPERATIONS COST-EFFECTIVENESS MEASURES

Several examples were listed in Chapter Five. There probably are more examples in the literature in this category than any other category of cost-effectiveness.

CATEGORY 6. CONSTRUCTION COST-EFFECTIVENESS MEASURES

As noted in Chapter Five, most of the examples to date in this category have dealt with "value engineering," the handling of detours, and construction during off-peak traffic hours, including nighttime construction.

CATEGORY 7. MAINTENANCE COST-EFFECTIVENESS MEASURES

The California Department of Transportation (Caltrans) has a series of cost-effectiveness methodologies for such items as improving or adding safety roadside rest areas, highway planting or planting restoration, constructing or improving vista points, and enhancing the roadside (*26*). Three examples are listed below.

HA25 Highway Planting Restoration

Program component HA25 is concerned with (a) restoration of existing highway planting and irrigation systems and, (b) to a lesser extent, with replacement of planting removed by new highway construction. The emphasis on reducing the cost of maintaining existing planting in HA25 permits the following benefit-cost ratio to be used as the project criterion:

BC/ratio = (AADT) (w_1 hazard reduction + w_2 irrigation inefficiency + w_3 age and appearance)/(500 × maintenance cost savings per acre project cost per acre)

where w's are weights to be assigned by Caltrans. In this ratio, an "effectiveness ratio" is first stated in the numerator, with weighted ratings of variables measuring the three main HA25 project objectives divided by 500, for a total potential ratio of 2. This effectiveness ratio is next multiplied by the present worth of savings in maintenance costs per acre, which often exceeds project costs per acre; so approximately equal weight is given to dollar savings and other project objectives.

HA26 Safety Roadside Rest Restoration

Program component HA26 is responsible for eliminating unsafe and unsanitary conditions at existing safety roadside rest areas, in addition to providing for facilities for the handicapped and operational improvements. The recommended criterion follows:

C-E index = AADT score × deficiency reduction project cost in thousands of dollars.

A scale is provided for rating the type and degree of deficiency reduction achieved by a project. The project ranking for priority purposes is then a function of AADT, deficiency reduction, and cost.

HB34 Vista Points and Roadside Enhancement

Only the construction or improvement of vista points—safe places to stop and view scenery of outstanding beauty—are rated in this program component, using the following criterion:

C-E Index = AADT score (w_1 scenic quality + w_2 alternative stops + w_3 deficiency reduction) project cost in thousands of dollars.

where w's are weights to be assigned by Caltrans. The numerator of the index utilizes ratings of the scenic quality of the vista point, its distance from other vista points, and, for improved sites, the degree of reduction in deficient conditions.

CATEGORY 8. PRIVATE-INVESTMENT COST-EFFECTIVENESS

In recent years, private developers have made substantial investments in highway improvements that, in the past, had been paid for by public funds. In some cases, these improvements were forced on the developer when the traffic impact of a required environmental assessment revealed that extremely poor levels of service would result from newly generated traffic.

Payments might be for an entire new interchange. In other cases, developers were required to make only a partial payment or donate land for the improvement or pay only for the design. This usually occurs when the improvement is on the state's construction program for a future year but has a relatively low priority. The desire of local officials to receive the economic benefits of the development and a contribution by the developer accelerate design and construction. Private investment, therefore, can change state priorities and shift state funds and staff away from other needed projects.

For smaller developments having a lesser impact on the highway system, some jurisdictions charge an "impact fee." This is a one-time fee collected by local governments from developers to generate revenue for capital funding by their development. Florida, with its requirement for developers to participate in a "development of regional impact review process" (DRI reports), has been a leader in this field. In some states, a similar process is triggered by a request for permit for a driveway onto a state highway. In cities, it will be triggered by application for a zoning variance.

In cases in which expansion of the state highway system to accommodate new, large volumes of traffic is not cost-effective, other traffic-mitigation measures must be proposed by the developer. These include various forms of transit (such as people movers and other transit systems), busways, vanpooling, staggered hours, etc. brought about by restrictions in highway capacity and/or on-site parking.

The fundamental question is: What combination of transportation services is most cost-effective for the developer and acceptable to the responsible highway authorities? The following is a theoretical case prepared by a developer who is very aggressive not only in trying to meet the needs of his own development but also in trying to improve traffic conditions in the area to make the development more accessible in the years ahead as traffic volumes continue to increase (*20*).

Assume that the development budget for a 300,000 s.f. office building is $50 million. The rent required to support the debt on the property can be calculated considering interest, loan period, and the lenders' financial requirements for the loan. The lender has independent appraisal done to determine whether the market can support this rent. But before reaching this step, the developer also makes a determination of the feasibility of the rent. If the rent looks too high, the budget must be pared down. For example, if the budget includes a $500,000 contribution for interchange improvements, the portion of the rent attributable to this cost component can be calculated.

The example described above assumes 100 percent financing. In the case where the developer (and/or an investor) has equity in the project, return on equity would be calculated. A multiyear pro forma budget would be calculated, making assumptions for vacancy rate, capital replacement reserve, re-leasing expenses, rent increases, and cost increases. A common method for return on investment would be to calculate the internal rate of return for the multiyear cash flow and developers' equity. A higher project cost would translate into either a larger equity or a smaller cash flow (resulting from a larger debt service from a larger loan). In either case, the return on investment would be decreased. The developer (or investor) would compare the rate of return with other opportunities (considering risk) to decide whether to go ahead with the project.

During the past two years there have been several conferences on this topic at which a number of papers have been presented. The previously cited reference (*16*) provides a well-presented series of papers that the reader should refer to for more details.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The nation's highway and bridge needs are increasing at a rapid pace—a pace that exceeds the ability of state and local government to provide the resources necessary to maintain minimum safe and acceptable levels of service. In addition, it is inevitable that the proportion of those needs to be funded by the federal government will continue to decrease as federal funding priorities change. Consequently, it is more important than ever before that state and local highway agencies carefully evaluate the most cost-effective solutions possible, as they continue to develop programs within severely constrained budgets.

The research conducted for this project resulted in the conclusion that some states have developed and applied practical and very useful analysis methods to develop cost-effective solutions to highway and bridge problems. More specifically, the research has resulted in the following conclusions:

- The application of cost-effectiveness measures is limited in most cases to the traditional cost/benefit analysis. Those analyses are not always used consistently within a particular state, and there is little uniformity from state to state. In general, there is only a limited analysis undertaken in most cases.
- The most prevalent cost-effectiveness measures appear to be those that are based on the use of sufficiency ratings, using the traditional elements of safety, structure, and service. The sufficiency ratings are modified by factors such as average daily traffic, cost, length of project, and sometimes a life-cycle cost analysis. Florida, Maine, Montana, and Texas provide good examples.
- The "systems analysis packages," such as HIAP, HEEM, and HPMS, are used by very few states. There appears to be a growing interest in the use of HPMS for statewide highway programming.
- Although increasing attention is being given to the use of private funds to pay for various transportation improvements, little or no analysis has been undertaken to determine the effectiveness or impacts of private sector funding. Private sector funds are being used to finance a wide range of transportation projects, including transportation system management-type projects, but also new interchanges and substantial highway mileage.
- The traditional cost/benefit analyses undertaken to justify the expenditure of federal funds for highway and bridge capital improvements are not necessarily the most relevant when considering the need to use state and local funds because those analyses give only a "unit" number result, not an answer that provides a "miles per dollar" or other cost-effectiveness measure.
- The reasons that states have not developed more systematic and rigid analysis methods to determine cost-effectiveness vary from place to place. However, these reasons include:
  — Need to collect large amounts of data.
  — Inadequate number of trained personnel.
  — Inadequate funding for planning and analysis.
  — No need to do such analysis, because critical highway and bridge needs are perceived to be so obvious.
  — Unacceptable reliability in using currently available analysis methods.
  — Lack of full comprehension and acceptance of these methods by decision-makers. (Even if they understood these methods, some might still want more flexibility in what, in the final analysis, is a political decision process.)
- Most of the states surveyed believe that it would be worthwhile to devote much more time, attention, and money to cost-effectiveness analysis.

In conclusion, this research has clearly illustrated the critical need for the development and implementation of better analysis methods to help guide a state to establish the most cost-effective programs possible.

RECOMMENDATIONS

An array of cost-effectiveness methodologies should be developed for the categories selected in this study. The categories should be reconsidered and standardized by a panel of transportation, highway, economic, and investment analysis specialists. Then, one or two cost-effectiveness procedures, as simple as possible, should be developed or improved for each category. Computer software, possibly obtained from one of the states currently using a selected procedure, should be developed and made available to all states and regional governments.

An integrated set of analysis procedures should be developed to allow for an evaluation of highway and bridge projects that fall into the following categories:

— New construction
— Reconstruction
— Rehabilitation
— Routine maintenance
— Safety
— Traffic flow improvement

The analysis procedures should also allow for evaluating the following kinds of trade-offs:

— Capacity expansion vs. TSM
— Short-term vs. long-term
— New construction or reconstruction vs. rehabilitation
— Urban vs. rural areas
— Public vs. private sources of funds

The development of such an array of analysis methods will be a very difficult task. However, there are a number of analysis procedures already available and in use that can provide the individual basis for establishing such a procedure. They include:

— Cost/benefit analysis
— Maintenance management systems
— Pavement management systems
— Bridge management systems
— Various traffic engineering analyses
— Sufficiency ratings for pavements and bridges
— NCHRP Report 263 (*27*) for low-cost TSM projects
— Equipment management systems
— Construction management systems
— Database management systems
— Value engineering
— Life-cycle costing
— Management information systems

As related to a DOT or highway department organization, the challenge will be to develop an integrated analysis capability that will provide the basis on which highway program managers can make decisions on the most effective use of limited funds available for a variety of highway, bridge, and related needs. The research illustrated the fact that only a few states have made significant progress in the development of a set of cost-effectiveness measures. Thus, there is a critical need to begin to implement the recommendations made in this report.

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