Structured Assessment of Benefits and Costs in Transportation Projects

Brad L. Steckler, P.E.
Manager, Engineering Studies Section
Indiana Department of Transportation (INDOT)

I. Introduction

Why structure a decision? After all, the process is a commitment of already limited time. Simply stated, proper assessment can improve one's judgement. Without structure, large matrices resulting from multiple and conflicting objectives and mixed sources of often less-than-perfect information are difficult to reconcile. Befitting the project at hand, the decision-maker should judiciously invest time and effort in the decision-making process. The payoff: Sound allocation/supply of meager resources to serve travel demand—essentially optimal transportation economics. (Proper evaluation of choices within a particular improvement project can call for an advanced understanding of transportation economics.)

Requisite tradeoffs commonly take place within a triangular evaluation framework. Matters of efficiency (money's worth) and effectiveness (satisfying objectives) frame most decisions. As well equity issues may broaden the scope. Structured decision-analysis often improves determination of the most efficient, effective and equitable strategy to satisfy a transportation need.

By way of thorough analysis and synthesis, structure yields a deeper awareness of the problem, enhancing recognition of costs and consequences of available alternatives. The process clarifies issues related to choice, often leading to identification of new, superior alternatives. Decision-analysis assists in building consensus for improvement strategies. Figure 1, aside, and Figure 2, next page, illustrate the process.

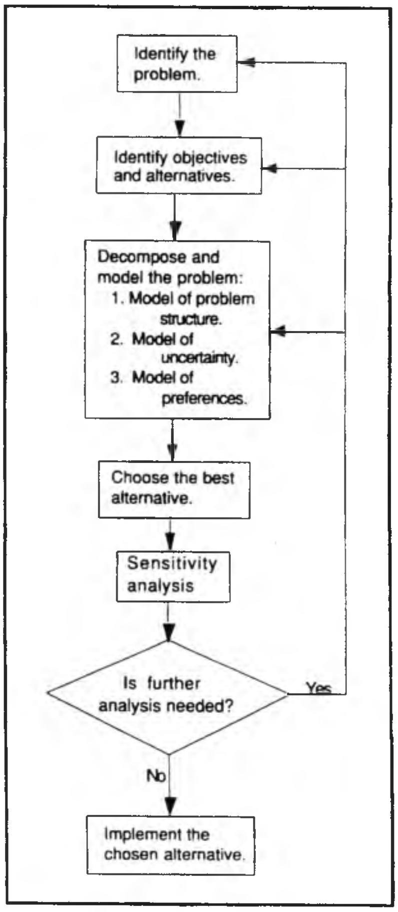

Figure 1—Decision Flow Chart (Source 1)

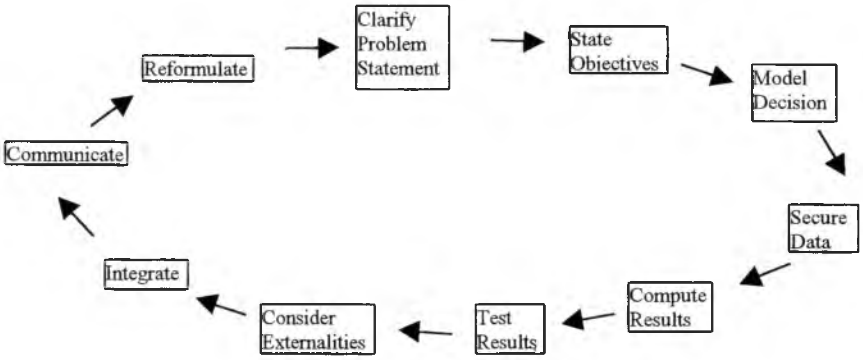

Figure 2—Problem Format

II. Background

Operations research (also called management science) is a branch of science devoted to perfecting techniques that facilitate good decision-making in a complex environment. No system could possibly take into account all factors. Questions arise regarding appropriate measures of worth, and associated units. Sensible decision-making inherently involves some semblance of valuation. Informed, subjective judgments are inescapable, and in fact critical in making sound decisions.

Decision-making is rarely a rigid process in a well-defined algorithm; rather it is iterative, with continual adjustments. Often the decision is straightforward, or lends itself to engineering judgment (heuristics) rather than extensive evaluation; in some cases it is complex, seemingly insoluble, requiring sophisticated evaluation of alternatives' consequences. Ultimately the path taken depends on the person(s) making the decision, the nature of the decision and the characteristics of alternatives deemed worthy of consideration.

III. Structuring Decisions

A. Influence Diagrams and Decision Trees

Where to start? Analysis begins with a graphical representation of the problem statement, relevant factors affecting the outcomes (including uncertain events) and the outcomes themselves. Figures 3 and 4 typify these approaches:

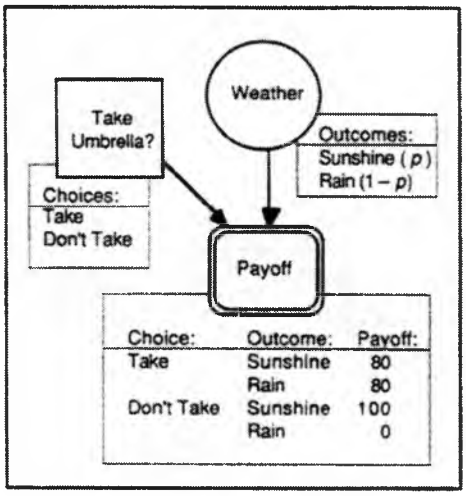

Figure 3—Influence Diagram (Source 1)

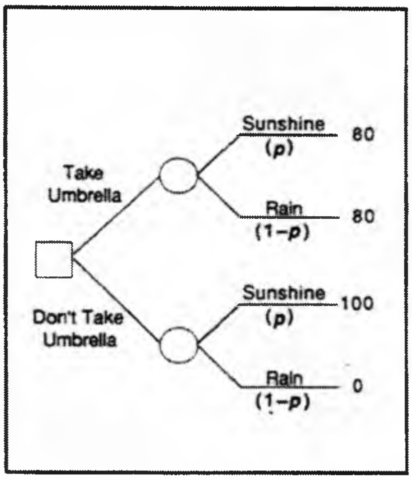

Figure 4—Decision Tree (Source 1)

B. With-Without vs. Before-After

Comparison of conditions with and without transportation improvements forms alternatives, as opposed to the facility's status before and after. The former approach isolates the relevant relationship.

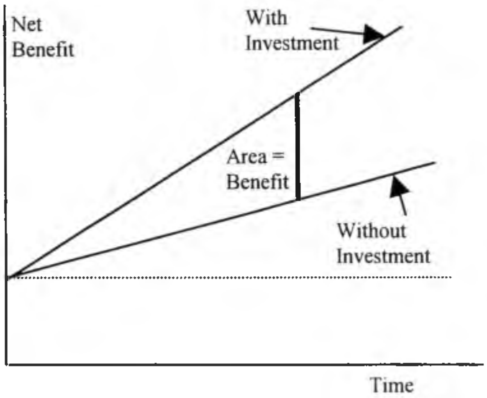

Figure 5—With-and-Without Scenario

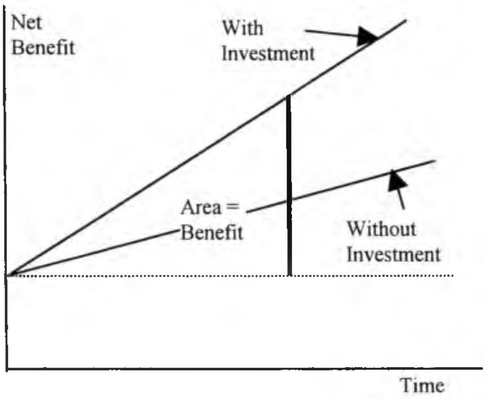

Figure 6—Before-and-After Scenario

IV. Methods

Three broad levels of decision analysis are outlined. What is described are strategies for making decisions, not decision rules. The processes vary in complexity. A critical distinction among the available techniques: the manner internal (user and sponsoring-agency) versus external (non-user) as well as market (economic) versus non-market (environmental and social) elements are assessed. (An externality may be priceable, e.g., the basis for congestion pricing.)

The first is labeled **Informal Analysis**. The name alludes to its comparatively casual approach. Judgment regarding optimal improvement strategy relies on "standard" procedure and intuitive balancing of agency costs, user benefits and external impacts. Second, **Engineering Economic Analysis** limits its horizon to user and sponsoring-agency components having a tangible market dollar value, in a life-cycle approach. Commonly known as traditional benefit-cost analysis, the procedure is fitting in projects having no appreciable non-user, environmental or social consequences. The last, **Cost-Effectiveness Analysis**, blends objective and subjective reasoning along with qualitative and quantitative measures into the decision mix. It is a more comprehensive form of benefit-cost analysis. Contemporary infrastructure improvement projects often have multiple objectives, demanding accounting of non-user, external consequences.

V. Informal Analysis

A. Type 1

Recognize that distinct elements of transportation plans often have been specified in advance. These typically published prior decisions are binding. They come in the form of adopted agency design standards and policies. For instance, the Indiana Design Manual dictates 3.6-m-wide travel lanes and full access control on rural freeways. These advance instructions result from judgments of economic worth. Projects having only a single improvement alternative essentially rely on these standards and policies for full description of the appropriate scope-of-work. Such cases call for no further decision-analysis.

B. Type 2

Even projects having more than one improvement alternative may warrant no structured approach to arrive at a sound decision regarding the best alternative. Often no more than cursory review of alternatives' costs, benefits and consequences is necessary to render a valid decision. Cases occur where one option clearly dominates all others with respect to stated project objectives (see Figure 7). Relevant issues affecting optimal choice are clear. Ranking is informal, but justifiable. Rigorous analysis is unnecessary in this scenario.

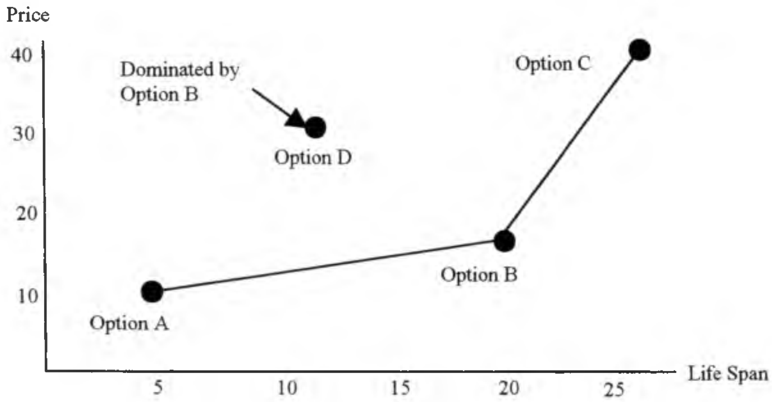

Figure 7—Dominance

VI. Engineering Economic Analysis

A. Overview, Application

Engineering economic analysis is the classical means for assessing public-works projects. The process historically has been the most widely used project-evaluation approach. Subjective influence imparted by the decision-maker is restricted. The potential weakness of this traditional form of benefit-cost (B-C) analysis is that it recognizes only tangible attributes. Non-monetary, external impacts, such as social and environmental consequences, receive no direct consideration. However, engineering economic analysis applies well in situations where non-user impacts are absent, minimal or identical for all alternatives, and user impacts have a market value.

B. Process

Comparison of transportation user benefits against project development costs, while incorporating the notion of money's time value, is the essence of engineering economic analysis. In general the process is moderately rigorous, and rigid. Traditional B-C involves a relatively well-defined algorithm. (Lacking computer applications tailored to this form of decision analysis, e.g., MicroBENCOST, the project engineer may find electronic spreadsheet software indispensable in bookkeeping tasks.)

Engineering economic analysis separates characteristics of each alternative into two categories: benefits and costs. All factors convert to dollar values. The accounting procedure: identify as benefits all user-related expenses (negative or positive) and as costs all agency-related expenses (negative or positive). Usually the existing facility, absent improvements other than routine maintenance, serves as the base (null alternative) against which are derived net benefits and costs. Convert future cash flows to present worth.

Hint: work in a real/constant domain, as it is analytically simpler than nominal/current. $(1 + z) = (1 + r)(1 + i)$, where r = real discount rate, i = inflation rate, z = nominal discount rate. Appropriate discount rates stand between 2 and 10 percent (real), with 5 to 7 percent a reasonable starting point. (Realize that the discount rate implies "opportunity cost of capital." The concept is exceedingly difficult to apply practically. No one really knows its true value.) Always test B-C results' sensitivity (what if?) to changes in key input variables possessing uncertainty, such as discount rate and economic life.

C. Benefit Side

Benefits reflect dollars spent or saved by users of the facility. The three traditional, basic road user-benefit (or dis-benefit) components: vehicle operation, occupants' travel time and crash likelihood. Other priceable factors may be included under particular circumstances. (Though published values are available from various sources, defining with confidence sheer dollar costs associated with fatal and personal-injury crashes is perplexing. The question arises as to what costs to include. One is cost to society; the other is "lost quality of life." The two lumped together compose a comprehensive crash cost. Considerable uncertainty exists with respect to expressing "lost quality of life" in monetary terms. As well, it is statistically difficult to predict and project rare events such as a fatal or personal-injury crash. In any case it is suggested that the decision-maker test B-C results to the sensitivity of a range of values for fatalities and personal-injuries.) Figure 8 portrays the source of user benefits:

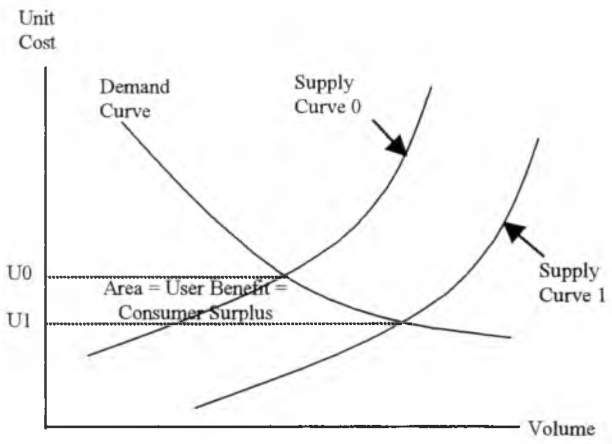

Figure 8—Transportation User Benefits

D. Cost Side

Costs are also measured in dollars. Sponsoring-agency (e.g., INDOT) costs are those associated with project development and construction. Terminal (salvage) value may be added, though views differ on gauging its worth. Recurrent, or annual facility-operation and maintenance costs and future rehabilitation outlays (or receipts) over the project's life cycle may be included, adjusted for money's time value.

E. Measures

Once benefits and costs have been identified and valued, the analyst is ready to compare, accept and reject alternatives. B-C results may be presented in various forms. Primary measures of project worth: net present value (NPV, also called net present worth, present value of benefits minus present value of costs), benefit-cost ratio (B/C, present worth of benefits divided by present worth of costs) and internal rate of return (IRR, rate generating NPV=0 and B/C=1). Each is valid. Use of NPV in describing alternatives' worthiness is preferable. NPV is the least ambiguous, the most straightforward. Note: B/C ratios between alternatives within a project cannot be compared directly; incremental, pair-wise comparison is essential.

F. Sources

Practical guidance in conducting traditional B-C analysis is accessible from various sources. Look to abundant literature affiliated with TRB, ASCE, AASHTO, FHWA and ITE, among other organizations and individuals having expertise in transportation and economic affairs. The following are specific sources normally accessible to practicing engineers, planners and other analysts: 1) Civil Engineering Reference Manual, latest edition, by M. Lindeburg; 2) A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements, 1977, by AASHTO; and 3) MicroBENCOST, latest edition, a software package for analyzing benefits and costs of highway improvements, by Texas Transportation Institute.

G. Computer Demonstration of MicroBENCOST

VII. Cost-Effectiveness Analysis

A. Overview

Cost-effectiveness (C-E) is a class of decision processes that incorporates user, non-user, market and non-market elements. The appraisal and program-monitoring technique assists the decision-maker during evaluation of projects generating intangibles (no dollar value) and externalities (secondary impacts). Though itself a form of, and often labeled, benefit-cost analysis, it differs from engineering economic analysis/traditional B-C in this regard: C-E attempts to provide a full accounting of costs, broad private, agency and social gains and losses. The more-comprehensive approach arose out of the awareness that it is difficult to convert credibly all major impacts into monetary terms, and that failure to internalize secondary impacts leads to inefficient allocation of transportation resources. As a matter of policy the act of pricing (attaching a dollar value to) intangibles is discouraged; more suitable means exist to account for such influences.

B. Application

Why and when should the project analyst resort to C-E analysis? Having a complicated or vague problem structure suggests forgoing informal and engineering economic analyses. Presence of numerous and conflicting objectives, externalities, intangibles, long time horizons, interest groups, multiple decision-makers, high stakes, etc., calls for some form of C-E. Note though that traditional B-C is not necessarily less rigorous, time-consuming or advanced than C-E. B-C simply disregards certain, external components. If these external impacts are clearly non-existent, negligible or equal among alternatives, then their influence on the decision is immaterial. Hence, traditional B-C or another less-advanced decision process is acceptable.

C. Cost Side

The cost side of C-E analysis, "efficiency" represents economic return on investment. It is a function of tangible costs, whether agency- or user-related. Also, costs can be internal (e.g., long-term maintenance) or external (e.g., adjacent streets' reduced congestion). Efficiency consideration is limited to elements having a tangible market value, lending themselves to dollar-value conversion. In this sense, measures such as net present value and benefit-cost ratio, derived from traditional B-C analysis, satisfactorily represent project efficiency and can be incorporated in C-E analysis.

D. Effectiveness Side

On the other hand, "effectiveness" is the degree in which an alternative satisfies project objectives, or need and purpose. Measures of effectiveness (MOE) may include mobility factors and such environmental impacts as air pollution and wetland encroachment, plus other difficult-to-price social consequences, e.g., noise and neighborhood disruption. The "best" alternative balances satisfaction of project objectives with project cost.

E. Subjective... and Fair

How to maintain impartiality? Selection of values within and importance (weights) of these MOE are sometimes derived subjectively, albeit impartially. The decision-maker should be aware of the implications of including in the decision process factors beyond those having a definite economic worth. The breadth of C-E decision-analysis necessarily involves eliciting decision-makers' subjective judgments, most often on importance of non-market externalities, e.g., wetland impact. This should not be viewed as a weakness, rather an essential step in arriving at a sound decision. The key is to conduct the study in a meticulous, unbiased manner, using available tools to reconcile the lack of a common basis (unit) to examine market- and non-market-based objectives. The analyst and/or requisite group of decision-makers is responsible for making reasonable judgments.

F. Available Processes

Whether C-E analysis can be labeled complex, robust or elegant depends on the specific method adopted. A host of available methods range from the rather simple (e.g., a chart of qualitative descriptions) to the highly sophisticated (e.g., stochastic modeling). A typical process: selected determinants, their magnitude and often their relative influence form a decision matrix, often "normalized" via scaling factors. Preference lies with C-E decision-making tools that break down the problem to successive steps, particularly with paired comparison of objectives and alternatives' component values. Ultimately the choice of a singular cost-effectiveness form should hinge on the decision-maker's desired level of precision in assessing the worthiness of project alternatives.

Some of the more common C-E processes and tools: ranking (ordinal), rating (cardinal), goals-achievement matrix, value matrix, expected value (weight each outcome by its probability of occurrence, then sum across potential outcomes), utility (single- and multi-objective theory), least-cost, preference function, risk/sensitivity/uncertainty, Monte Carlo simulation, tornado diagrams, graphical overlays, decision trees, Impact Index Method, Analytic Hierarchy Process (AHP, melds mathematics and psychology), and Delphi technique, among many more.

G. Sources

A quickly expanding supply of information useful to the analyst is available from familiar institutions. As with traditional, engineering economic B-C analysis, seek direction on cost-effectiveness procedures from TRB, ASCE, AASHTO, FHWA, ITE, etc. A few other sources: Making Hard Decisions, 1991, by Robert T. Clemen (Source 1); The Principles and Applications of Decision Analysis, 1983, by Ronald A. Howard and James Matheson; Applied Decision Analysis, 1984, by Derek Bunn; Microeconomics, 1992, by Robert S. Rubinfeld; and Economic Analysis of Agricultural Projects, 1982, by J. Price Gittinger.

VIII. Software Applications, A Taste

A. Expert Choice (AHP)

B. @ RISK (Monte Carlo simulation)

IX. Conclusion

Governments have a significant presence in the transportation sector. Good projects reinforce an effective network-wide transportation plan. Sound project preparation and decision-analysis must be strategically positioned under the umbrella of a broader development plan. Project-specific structured assessment of benefits and costs can enhance allocation of scarce resources; however, it alone cannot assure ideal balance of overall objectives—satisfaction of an agency's mission.

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