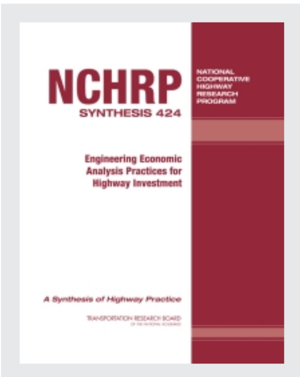

Engineering Economic Analysis Practices for Highway Investment

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 424

Engineering Economic Analysis Practices for Highway Investment

A Synthesis of Highway Practice

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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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Managers in the several case-example agencies took the additional time to define and describe their proposed case, send documentation of relevant information, participate in follow-up telephone interviews, and review drafts of their respective cases. A heartfelt nod of appreciation and gratitude goes to the following managers who contributed so positively to the case examples: Mark Seaman, Senior Economist, Port Authority of New York and New Jersey, for the Critical Interstate Transportation Facilities case; Pat Morin, Manager, Systems Analysis & Programming; Faris Al-Memar, Manager, System Analysis & Planning; and Kumiko Izawa, Traffic and Collision Analysis Engineer, all with the Capital Program Development & Management Office, Washington State DOT for the Planning and Programming: Mobility and Safety Projects case; Michael B. Johnson, Chief, Office of Specialty Investigations & Bridge Management, Structure Maintenance & Investigations, California DOT for the Bridge Project Programming and Permitting case; Louis H. Adams, Acting Director, System Performance & Asset Management Bureau, New York State DOT for the Economics-Based Tradeoff Analysis case; Robert R. Locander, Pavement Design Engineer, Materials and Geotechnical Branch, Colorado DOT for the Pavement Type Selection case; Thomas Van, FHWA; Kurt Lieblong, State Production Support Engineer, Florida DOT; and Troy Tusup, Value Analysis Program Manager, California DOT for the Value Engineering case; and John L. Wilson, Economic Policy Analyst, Office of Capital Programs and Performance Measures, Minnesota DOT for the Acceleration of Project Delivery case; with earlier contributions provided by Abigail McKenzie, (formerly) Director, Office of Investment Management (now retired); and Ed Idzorek, Office of Capital Programs and Performance Measures, Minnesota DOT.

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FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Jon M. Williams
Program Director
Transportation Research Board

This study has looked at how U.S. transportation agencies have applied engineering economics (benefit–cost analyses and similar procedures) to decisions on highway investments. State departments of transportation (DOTs) are most likely to use economic methods when considering investments in pavement and bridge preservation, safety improvements, and major projects on trunk lines and in urban areas. This study, however, has found agencies that use economic information across their key business and decision processes.

Information was gathered through literature review, presentations at conference committee meetings, a screening survey of state DOTs, and interviews leading to case studies.

Michael J. Markow, Teaticket, Massachusetts, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

ENGINEERING ECONOMIC ANALYSIS PRACTICES FOR HIGHWAY INVESTMENT

SUMMARY

To paraphrase a recent study in performance management: Although the bureaucratic tendency in government is often to avoid doing something wrong, economic analyses can demonstrate that public agencies actually do something right. This synthesis has looked at how U.S. transportation agencies have applied engineering economics—benefit–cost analyses and similar procedures—to decisions on highway investments. Although benefit–cost calculations are often regarded as methods of project appraisal, occurring early in planning and design, experience shows that these methods have been successfully and productively applied throughout the project life cycle. Most U.S. state departments of transportation (DOTs) actually conduct economic analyses for at least certain types of highway investments. Past research suggests that the most widely used applications of economic methods occur when considering investments in pavement and bridge preservation (a practice correlated with economic algorithms in pavement and bridge management systems), safety improvements (considering the social costs potentially avoided by reducing fatalities, injuries, and property damage resulting from collisions), and major projects on trunk lines and in urban areas. What the findings of this synthesis have demonstrated, however, is that more broad-based applications of engineering economic analyses are conducted by agencies that are conversant in economic concepts and methods to a greater than average degree. These agencies have developed a level of proficiency that enables them to integrate economic analyses throughout their daily operations.

Agencies that successfully apply engineering economic analyses across their business processes strive to develop and maintain the tools and capabilities to perform these analyses effectively, but in a practical, common-sense way. These tools and capabilities include effective guidance and executive support, staff knowledge and skills, financial and administrative resources, the incorporation of appropriate analytic methods within business processes, effective data collection and analysis, accessible information technology systems, and supporting institutional relationships with other organizations. The perspective is fundamentally one of incorporating economic analyses within the normal, routine business processes that an agency must perform to do its job effectively, rather than one of viewing economic analyses as additional, somewhat isolated, adjuncts to other activities. Executives in these agencies value economic information on proposed highway investments. Their managers and staff work diligently to develop and maintain the capabilities needed to provide this information for key business and decision processes.

Case examples have been critical to developing the findings of this synthesis. Several mechanisms were used to identify candidate agencies: a literature review, presentations at conference committee meetings, interviews with topic panel members and other industry experts, and a screening survey. The screening survey questionnaire was sent to state DOT representatives on AASHTO's Standing Committee on Highways, with copies to each state DOT's Research Advisory Committee member, and a corresponding questionnaire to each state's FHWA division office. Responses were received from 17 state DOTs and 8 FHWA division offices. For two states, responses were received from both the DOT and the FHWA division office; these were combined to produce a single response for each state, resulting in 23 unique state responses. Of these 23 responses, 20 states reported using engineering economic analyses, whereas 3 described themselves as not using such analyses. The 20 affirmatively responding states were considered as candidates for case examples; the 3 states that responded negatively

provided reasons why their state highway agency did not use economic analysis on a routine basis. The survey results were used solely as a screening device to identify candidates for case examples and to obtain background information on usage patterns. The synthesis survey results were consistent with previous research and with findings of other study surveys. The survey data, together with findings from the other sources identified previously, resulted in the selection of nine categories of case examples illustrating 12 distinct economic analyses.

The case examples cover the following stages of project and program development and delivery:

- **Planning:** a case example of Critical Interstate Facilities owned and operated by the Port Authority of New York and New Jersey, with a supporting economic analysis of maritime shipping to the Port of New York and New Jersey performed by the U.S. Army Corps of Engineers; and a case example in Mobility Planning by the Washington State DOT.
- **Programming and Budgeting:** two case examples illustrating methods used by the Washington State DOT for Mobility Programming and Safety Programming; one example by Caltrans for Bridge Programming and Permitting, including environmental permitting issues; and a case illustrating methodological development for Economics-Based Tradeoff Analysis by the New York State DOT.
- **Resource Allocation Following Budget Approval:** the New York State DOT case example on Economics-Based Tradeoff Analysis could apply at this stage as well.
- **Project Design and Development:** this aspect of project delivery is addressed by the Pavement Type Selection case example, which compares practices of two state DOTs (Colorado and California); and by the Value Engineering case example, which likewise compares practices of two state DOTs (California and Florida).
- **Project Construction Options:** this aspect of project delivery considers different construction or design-plus-construction options, which are considered in the Acceleration of Project Delivery case developed with the Minnesota DOT.

The case examples illustrate not only the application of engineering economic methods to various decisions in highway investment, but also the particular practices used by agencies in building such analyses; for example, compiling data, selecting a discount rate, accounting for risk or uncertainty in estimates, and defining alternatives. The case examples represent a variety of program areas (e.g., preservation, mobility, and safety), stages of the decision process (e.g., planning and programming), and levels of the system analyzed (e.g., link or project, corridor, program, and network). Viewed individually, the case examples show how engineering knowledge and a need to understand the impacts of particular decisions can be organized within a practical economic framework. Viewed collectively, however, the case examples begin to reveal characteristics that are held in common among agencies successfully applying engineering economic practices across a wide range of applications.

Several characteristics differentiate agencies that are conversant in economic methods, involving aspects of an agency's makeup and its approach to solving transportation problems and needs:

- The influence of organizational champions and culture;
- A level of knowledge, proficiency, and comfort regarding use of economic methods;
- A tighter integration of business and decision processes that make economic analyses a part of routine business rather than a distinct, somewhat isolated task;
- The willingness to be creative in defining alternative solutions, and to innovate in devising the methods and measures of analysis;
- The fact that upper management asks for and uses the results of economic analyses in its decision making;
- The availability of information technology to support not only the economic analyses but also important steps such as diagnosing problems, defining realistic alternatives, and displaying results;

- The training of staff and provision of resources such as formal guidelines and websites on economic concepts and methods; and, perhaps most importantly;
- The recognition that economic outcomes are an integral part of gauging highway system performance.

A component of the study explored the benefits of economic analyses to an agency. These benefits were found in two broad categories. The first comprised the direct or tangible benefit of an economic result that demonstrates the value or merit of a highway investment. This value often represents a benefit received by road users or costs that are avoided by them and by the agency. Monetized benefits help in understanding the tradeoffs among competing highway investments. The second category is the indirect or intangible benefit of encouraging a better decision process within the agency organization. Once a culture supporting economic analyses is established within the organization, these analyses provide incentives to identify all realistic alternatives to solve highway needs, maintain a focus on the purpose of the proposed investment and avoid unneeded additions of "nice to have" features to a project, avoid biases toward familiar or traditional solutions (such as particular pavement materials), and support these objectives through clear guidance and communication, backed by adequate resources to accomplish the analyses effectively.

Although the case examples represent success stories, there are also impediments to the wider application of engineering economic analyses. Studies by the General Accountability Office and FHWA have identified challenges in two areas: the methods of analysis themselves, and how these methods are applied by practitioners. With benefit–cost analysis as an example, the methodological problems include that the benefits are computed in the aggregate, without regard to who receives them; the monetization of benefits is not standardized, and researchers may disagree on given valuations; and existing models are unable to predict accurately certain key effects of transportation investments, such as resulting changes in land use, driver behavior, and diversion of traffic to alternate routes or modes. Challenges in the use of these models relate largely to human error, the lack of good data, complications resulting from how independent projects might be combined (or not combined) in the analysis, uncertainties in forecasting, and a tendency to overlook potentially critical elements of the analysis.

A number of these latter types of problems were revealed in the 2009 FHWA review of TIGER (Transportation Investment Generating Economic Recovery) grant applications, which required an economic analysis of project submittals that were competing for funding. These findings were important, because the TIGER program has been proposed as a possible model of competitive, performance-based federal transportation funding in the future. The GAO has likewise reviewed the TIGER grant applications, and came to similar conclusions regarding the variable quality of the economic analysis submittals and limitations on their usefulness.

The synthesis has proposed several recommendations for research to help correct problems in existing models and deficiencies in current practice. Some of these are drawn from experience overseas, gained through a prior international scan, and the literature review conducted in this present study. Among the research recommendations are the desirability of improved skills in conducting economic analyses to reduce the human errors alluded to earlier. Possible mechanisms include training sessions, peer exchanges, webinars, and self-training tools, to name some candidates. Another recommendation, prompted by overseas research, is the conduct of ex-post or post-construction analyses of actual economic performance of an investment based on a completed, operational project. By comparing actual results with those that had been predicted during project appraisal, agencies can improve their methods, data, and assumptions used in economic analyses. This study recommends research to develop the structure and protocol of these post-construction analyses. Other research recommendations are included in the conclusions to this report.

CHAPTER ONE

INTRODUCTION

BACKGROUND

Engineering economic analysis applies economic concepts and methods to engineering problems to support decisions on a best course of action. Within highway transportation, these decisions typically involve selection of the preferred alternative among projects or levels of service affecting highways, roads, or streets. Engineering economic analysis provides a way of comparing the economic gains expected from an investment with the cost of that investment; providing an objective understanding of value to be expected for cost incurred. Because the service lives of highway facilities that are properly maintained extend for decades, and the value gained from highway investments and subsequent expenditures may not be fully realized until years after the actual outlays, engineering economic analyses (EEAs) cover a period of time sufficient to capture these positive and negative economic flows. In contrast with private-sector investments, public-sector projects and services, including those analyzed in highway transportation, do not generate tangible income streams or direct monetary payments as economic gains. Rather, the economic value of a highway project or service is reflected in benefits to the public, typically gauged as reductions in their costs of travel, or in potential costs to the highway user or the highway agency that are avoided. Avoided costs occur, for example, when an existing level of congestion is reduced, when the potential risk of an accident is removed, when sources of harmful pollution are eliminated, or when potential deterioration of the highway facility is prevented.

Engineering economic concepts and methods include, but are not limited to, life-cycle cost analysis (LCCA), benefit–cost analysis (BCA), present-worth analysis, measures of cost-effectiveness, and cost avoidance as a concept of benefit. These may be applied at one or more stages of a project life cycle, such as planning, project scope development, programming (including ranking, project selection, and budgeting), resource allocation, best-value procurement, project design and development [including value engineering (VE) at the preliminary engineering or concept development stage], construction (e.g., analysis of options for accelerated project delivery), and operation and maintenance. Engineering economic analysis may also be used as a tool following completion of a project or service to infer corrected values of key parameters. It can provide the framework to synthesize information and knowledge from a completed effort, enabling development of a new analytic tool to analyze similar projects or services in the future. Economic analysis algorithms may be embedded in an agency's infrastructure management, congestion management, and safety management systems, or may be part of an overall asset management approach.

Analyses of highway investments benefit from EEAs in several ways:

- Highway investments provide benefits that extend into the future, typically measured in years or decades. Engineering economic analysis provides the multi-year framework needed to capture these benefits in a fair comparison of benefits to costs.
- A level of long-term structural performance can be provided by different patterns of road investment, varying the purpose, magnitude, and timing of capital and maintenance expenditures. Engineering economic analysis provides a way to analyze these alternative investment streams, identifying the most efficient approach to achieving desired performance and road-user costs or benefits.
- Budget limits and other constraints may prompt an examination of what level of performance might be sought in a highway investment. Tradeoffs exist among project and corridor location, design concept, level of highway development, maintenance policy, operating policy, and costs and benefits accruing to road users as well as nonusers. Engineering economic analysis provides a way to sort through these options on a level playing field, using the common metric of monetary value.
- Highway programs consist of different needs and types of projects and services. Tradeoffs exist in the funding of these competing needs, a process state departments of transportation (DOTs) face in programming, budget development and recommendation, and resource allocation. Engineering economic analysis can provide information on the consequences of different levels of investment among a diverse set of programs in a consistent, monetized framework to help in these decisions.
- Highway investments also may entail significant impacts in environment, energy, materials usage, economic vitality, and quality of life, in both monetary and nonmonetary terms. Even when it is not possible to quantify all impacts in dollars, the framework provided by an engineering economic analysis can provide a useful point of departure for organizing qualitative as well as quantitative information about highway investment options.

- State DOTs recognize their stewardship responsibilities in preserving and operating the significant investment in the existing highway system. Those responsibilities entail informed decisions on how, where, and when to invest public tax dollars to maintain and improve that system. EEA can help at all stages of investment decision making, from long-range planning through best-value bid evaluation, and from VE during initial construction to analysis of alternatives in operations, maintenance, rehabilitation, and reconstruction expenditures throughout asset service life.

DEFINITIONS

The following definitions are used in this report:

- Agency costs—Costs borne by a transportation agency for a project or service: typically includes direct and indirect costs of planning and design; construction, installation, or service commencement; maintenance; operation; rehabilitation, replacement, or reconstruction; and discontinuation, abandonment, or salvage if appropriate.
- Benefits—Gains, reductions in costs, or costs avoided as the result of performing a project or service. (See also disbenefits.)
- Benefit–cost analysis—An analysis comparing the benefits generated by a project or service to the costs incurred for the project or service over the period analyzed (the "life cycle"), with results expressed as the ratio of benefits to costs [adapted from *AASHTO Transportation Glossary* (2009) and *Asset Management Overview* (2007)]. [Used synonymously with cost–benefit analysis in this report. Results of a benefit–cost analysis, or BCA, are described variously as benefit–cost ratio, B-C ratio, or B/C.]
- Cost–benefit analysis (CBA)—Comparison of the costs associated with a specific action to the benefits derived from that action, as compared in an analysis period (the life cycle) [adapted from *AASHTO Transportation Glossary* (2009) and *Asset Management Overview* (2007)]. (Cost–benefit analysis, or CBA, is used synonymously in this report with BCA.)
- Cost-effectiveness—A general measure indicating that a project or service is economical in terms of identifiable benefits produced for the money spent. The measure is "general" in that benefits may or may not be monetized. For example, an action having an incremental benefit–cost ratio exceeding 1.0, where both benefits and costs are expressed in dollars, may be said to be cost-effective. Actions that maximize nonmonetary benefits; for example, in terms of reduced fatal accident rate per dollar spent, or increase in pavement quality per dollar spent, may also be said to be cost-effective [adapted from *AASHTO Transportation Glossary* (2009) and "Transportation Benefit–cost Analysis" (2010)].
- Disbenefits—Economic losses or increases in costs incurred following performance of a project or service, where benefits might have otherwise been expected.
- Discount rate—A percentage rate that accounts for the time value of money when performing an economic analysis of alternatives [adapted from *AASHTO Transportation Glossary* (2009)]. It is interpreted as an opportunity cost of capital; that is, the economic cost of investing money in public works for which no return in direct monetary income is expected (adapted from Winfrey 1969). The discount rate is also referred to in the literature as the economic discount rate and the social discount rate. (See chapter two for further discussion of the discount rate.)
- Engineering economic analysis (EEA)—An analysis of alternatives for a proposed engineering project or service to determine the relative worth of net economic gains expected from each alternative in relation to the net economic costs required to produce those gains, all compared for a designated analysis period (adapted from Winfrey 1969).
- Economic impact analysis (EIA)—An analysis of the effects that a project or service has on the economy of a defined area, measured by resulting changes in business output, jobs, income, or tax revenue. Positive changes are benefits; negative changes, disbenefits. Although important in the context of local economic prospects, economic impacts are not included in benefit–cost analyses (BCAs) for reasons explained in other sources [e.g., "Transportation Benefit–Cost Analysis" (2010) and *Economic Analysis Primer* (2003)].
- Financial analysis—An analysis of how to pay for agency projects and services, which encompasses but is not limited to estimates of taxes, fees, and revenues; analysis of options for borrowing and interest payments thereon; consideration of payments or contributions by other organizations or entities; development of agency financial plans (e.g., revenue and expenditure forecasts across projects or programs); assessments of proposed projects and services regarding their eligibility for potential funding sources ("colors of money" analyses); budgeting; and treatment of cost inflation.
- Highway user costs—see Road user costs.
- Inflation—Discussed in two ways: general inflation and differential inflation:
  - General inflation—price changes across a broad-based mix of goods and services, often expressed as an annual percentage, although other time periods could be used.
  - Differential inflation—a price change affecting a particular good or service, which is different from and not reflected materially in the general inflation rate; often expressed as an annual percentage, although other time periods could be used.
- Interest—Amount of money paid for use of borrowed money or debt; also referred to as the "rent" or debt service on a loan. Interest payments are usually expressed as a percentage (e.g., annual or monthly percentage of the total amount borrowed, or of the loan amount or debt remaining).

- Life-cycle cost analysis (LCCA)—An economic assessment of competing project or service alternatives, considering all significant costs of ownership (agency costs) and use (road user costs) over the economic life of the project or service, expressed in equivalent dollars [adapted from *AASHTO Transportation Glossary* (2009)]. Also referred to as "whole-life" analysis. An LCCA is in contrast to an "initial cost" or "first cost" analysis, which ignores events and costs following the initial investment.
- Road user costs—Costs incurred by personal or commercial users of a roadway, typically encompassing costs associated with travel time, vehicle operation, and accidents. [Other cost components may also be included; for example, economic valuations of contributions to air, water, and noise pollution; and costs associated with unreliable (or varying) travel times.]
- Tradeoffs—Comparisons of alternative solutions and their consequences, typically where these alternatives are generated by reallocating funds among competing programs [adapted from *Asset Management Overview* (2007)].

These definitions cover key terms used in EEAs generally. Other terms related to specific situations or cases will be explained later in the report, because their definitions and uses are more easily and meaningfully understood in context.

As the definitions indicate, this report distinguishes between economic analyses and financial analyses of highway investments, subjects that both involve streams of dollars and therefore can easily become confused in practice. For example, questions may arise in an economic analysis on whether or not to include inflation; whether to use base-year or current-year dollars; the differences between an interest rate and a discount rate; and how to handle funding contributed toward a project by others that reduce the project's apparent cost to the highway agency. Table 1 identifies several of these factors related to project assessment and their interpretation in an economic context and in a financial context. Brief explanations highlighting differences between the two analyses are given; further details are covered in subsequent chapters, presenting both recommended guidance and case examples from actual agency applications. It is possible that a project can be economically feasible (it is worth doing), but financially infeasible (it cannot be paid for). The opposite is also true: a project can be economically infeasible (it is not worth the expenditure of taxpayer dollars), but financially feasible (money can be found to pay for it, but it would be a poor use of tax dollars). Table 2 illustrates these and other combinations of economic and financial possibilities to help solidify the differences between the two types of analyses. This synthesis focuses solely on the economic analysis of agency investments.

The definitions articulate several types of alternatives that are suitable for economic analyses; for example, road projects, services, and operating policies. Even activities such as data gathering and highway research could be subjects of EEA to analyze decisions among choices. For brevity, all of these options will be referred to simply as "projects" in the remainder of this report.

PERSPECTIVES ON ENGINEERING ECONOMIC ANALYSES

The concept of an economic benefit resulting from a public investment has long been understood in the U.S. road industry. In his textbook on LCCA, Winfrey cites several passages by William Gillespie, a 19th century author of a manual "on the principles and practices of road-making." Among the citations are the following:

> . . . Rapidity, safety, and economy of carriage are the objects of roads. They should therefore be so located and constructed as to enable burdens, of goods and of passengers, to be transported from one place to another, in the least possible time, with the least possible labor, and, consequently, with the least possible expense. . . . A minimum of expense is, of course, highly desirable; but the road which is truly cheapest is not the one which has cost the least money, but the one which makes the most profitable returns in proportion to the amount which has been expended upon it. *Source:* Quotes of William M. Gillespie cited by Winfrey (1969).

Although the nomenclature is somewhat different today, this concept is essentially that of a benefit conferred on road users through the expenditure of public dollars for roads. This notion of benefits justifying costs was eventually codified at the federal level for civil flood control facilities in the Flood Control Act of 1936 (P.L. 74-738, June 22, 1936). The application of a BCA, or equivalent calculation, is now a recognized methodology in many sectors of U.S. public policy, including transportation. Later chapters and appendices provide additional information on the nature of economic-analysis guidance at federal and state levels, and a series of case examples illustrating state DOT application of EEA.

Modern applications of EEA to highway systems could be said to have begun in the late 1960s, with the sponsorship by The World Bank of its Highway Design and Maintenance (HDM) Standards study. This study built on active research in road user costs and the emerging technology of computer hardware and software, including programs that addressed highway design, road surface deterioration and maintenance, and highway cost estimation. The result was the Highway Cost Model, a simulation model built on tradeoffs among road design and construction, road maintenance, and road user costs, with the objective to minimize life-cycle costs. This model was subsequently investigated through field studies of different road characteristics and vehicle fleets on several continents, as well as exercises in the economic analysis of road design and maintenance options, funded by The World Bank and other international lending institutions. The World Bank efforts resulted in the HDM series of computerized highway analysis systems.

TABLE 1
COMPARISON OF ECONOMIC AND FINANCIAL ANALYSIS FACTORS

Factor	Economic Analyses	Financial Analyses	Remarks
Purpose	To assess, from an economic standpoint, whether the project is worth doing	To determine whether and how project costs can be paid for	
Monetary measure	*Constant* dollars recommended, calibrated to a defined base year	*Current* (or year-of-expenditure) dollars	Refer to FHWA Primers and AASHTO Glossary
Interpretation of dollar inflows	Benefits to agency and to highway users (and possibly non-users)	Funding applied from all sources for which the project is eligible Project-generated revenue stream if applicable	
Interpretation of dollar outflows	Costs incurred throughout the project life cycle, including those for design, permitting and approval, construction, operation, maintenance, and rehabilitation, reconstruction, or replacement	Expenditures incurred throughout the project life cycle (see previous column) plus cost of financing (e.g., interest on loans or bonds) and cost escalation or inflation	Removal and salvage may also be considered in the project life cycle if appropriate to the category of work. Salvage may reflect a negative cost (i.e., a reduction in cost).
Considers general inflation?	No, general inflation should be excluded. However, differential inflation related to a given cost item may be considered when substantially different from the general inflation rate (e.g., a differential inflation in specific materials or energy costs).	Yes. General inflation affects budget costs and may also affect tax revenues if taxpayer behavior is price-elastic. Differential inflation should also be considered to include possible constraints on materials or energy supplies, and changes in technology affecting price.	
Representation of time-dependent effects on dollar streams	Addressed through a discount rate reflecting the opportunity cost of capital or a time value of money It is recommended that the discount rate not include inflation.	Addressed through a rate of inflation reflecting the change in purchasing power of a dollar calibrated to a base year If borrowing is involved, an interest rate captures the charge for borrowing to help fund the project.	Refer to chapter two for interpretations of the discount rate and OMB and FHWA guidance, and to chapter three for methods of setting the discount rate used by state DOTs.
Applicable time period	Duration sufficient to establish periods of equivalent performance among alternatives, encompassing initial construction plus later maintenance, operating, and rehabilitation actions as well as a period in which project benefits accrue to the agency and to road users.	Duration sufficient to encompass the period for which a firm is responsible for financial performance of a project. The period may encompass the time of project expenditures for initial construction plus later maintenance, operation, and rehabilitation; the period of repayment of borrowed funds, if any; and a period in which revenues are generated by the project.	
Are partial payments (funding contributions) by others included in project "costs" (e.g., as part of a B/C analysis)?	Any payment for this project incurs an opportunity cost—it cannot be used for another purpose. Since economic analyses deal with project worth, all payments by whoever are included in project "costs."	Payments by others reduce an agency's financial commitment to the project—i.e., they reduce its own budgeted costs. Financial plans and budgets would therefore assign only the reduced cost to the agency.	
Example methods	Net present value; equivalent annual costs and benefits; incremental benefit-cost analysis; incremental rate of return analysis	Cash-flow analysis of pay-as-you-go financing; repayment analysis for bonding or loans.	See report text (chapter two) for references to economic methods, and chapter three for case examples.

Note: OMB = Office of Management and Budget.

TABLE 2
ECONOMIC VERSUS FINANCIAL ASSESSMENTS OF CANDIDATE PROJECT SOLUTIONS

Financial Feasibility → Economic Justification	Financially Feasible	Financially Infeasible
Economically Justified	Solution is economically worth doing. Its benefits justify its cost. Among the alternatives considered, the solution maximizes benefits to the public. Solution is financially feasible; i.e., funding is available in the amount and timing needed to pay for the candidate project, including anticipated cost inflation. Implication: with good management of delivery, a worthwhile project can be completed for the available budget.	Solution is economically worth doing. Its costs are justified by its benefits to the public. However, funding is not sufficient to cover estimated costs including inflation, or the candidate project is ineligible for funding in the amount and schedule needed. Implication: while the solution would be worth implementing, it cannot be paid for given the current design and funding forecast. The candidate project should not be recommended. Other solutions to the need/problem that are feasible financially should be explored.
Economically Not Justified	Solution is economically not worth doing. Its benefits do not justify its cost. Unless justified by other, noneconomic considerations the project could be seen as a waste of taxpayer money. Funding is available to support the candidate project if it were worthwhile to do. Implication: consider revisiting the original need/problem to explore other solutions that are stronger economically; i.e., that increase benefits or reduce costs. Otherwise, consider redirecting the funding to viable project candidates that address other needs.	Solution is neither economically nor financially defensible. Even if there were other, noneconomic reasons to consider the solution, funding in the amount and timing needed is not available. Implication: reassess the original need/problem to gauge its priority relative to other needs. If priority is relatively high, develop new, economically viable solutions and consider other financing options (including innovative funding mechanisms or redirecting funding from lower priority project candidates) to fund the solution. Otherwise, move on to other needs and solutions.

Work proceeded through the 1970s to broaden applications of computerized systems to life-cycle economic analyses of highway investments, including developments in road preservation (e.g., pavement management and bridge management systems), mobility (e.g., urban travel demand models, intercity surface transportation planning models, and congestion models), and safety (e.g., work zone safety models). Several case examples in chapter three discuss software currently used by respective agencies to generate economic results, illustrating the mature products that have resulted from this history. Computerization of life-cycle economic calculations has not only permitted economic analyses to be done efficiently, but has also facilitated additional capabilities in risk analysis by speeding the production of sensitivity and scenario analyses, Monte Carlo simulations under risk and uncertainty, and bracketed sets of analyses (all of these to be explained in chapter two). Today there is a renewed interest in economic analyses that is driven by the increasing focus on performance accountability as well as experiments with new methods of nationwide project competition for funding [specifically the FHWA's TIGER (Transportation Investment Generating Economic Recovery) grant process, which likewise will be covered in chapter two]. This synthesis updates *NCHRP Synthesis 142: Methods of Cost-Effectiveness Analysis for Highway Projects* (Campbell and Humphrey 1988).

This history notwithstanding, research has shown that there is a good deal of variability nationwide in how state DOTs now use the information produced by EEAs, and at what organizational levels. The value of economic concepts and methods—in terms of the discipline and rigor they impose on structuring a solution, their analytic capability to address a number of practical problems, and the insights they provide to decision makers—is not always appreciated or understood. Underlying these generalizations is a varied set of practices:

- Many pavement management systems (PMSs) have cost-estimation algorithms that forecast agency costs for pavement maintenance, rehabilitation, and reconstruction. Some PMSs also include road user costs, which forecast the economic costs of congestion delays in work zones. This user-cost computation adds a premium to the cost of pavement repairs, encouraging strategies that provide longer-lasting pavement performance. Analytic tools have also been developed for pavement type selection, a consideration in pavement design. Type-selection analyses appear to be the most widely accepted, consistently applied demonstrations of LCCAs in U.S. highway program practice. One of the case examples in chapter three presents survey findings by others on this topic and reviews the type-selection practices of two state DOTs.

- Other highway infrastructure assets are not as widely subjected to decisions based on economic criteria, even when relevant management systems include built-in life-cycle analyses. *NCHRP Synthesis 397* found that although agencies do use economic methods to varying degrees in managing bridge programs, overall the practices do not represent wide use, particularly at senior management levels (Markow and Hyman 2009).
- Regarding other highway assets such as signs, signals, pavement markings, culverts, sidewalks, and roadway lighting, *NCHRP Synthesis 371* found that LCCAs are performed to some degree on a case-by-case basis to evaluate alternatives in components or materials. Several areas of potential improvement include a need for more definitive and reliable data to support LCCA of these assets, a need for measures of benefits and other impacts of decisions, and incorporation of LCCA within decision-support tools (Markow 2007).
- A number of agencies apply BCAs to safety improvement projects (Hanley 2004). The challenges in analyzing the economics of safety projects are to develop realistic forecasts of accident frequencies and the contributions of safety projects to reducing these frequencies, and to quantify the economic costs attributable to different severities of collisions.
- In its review of capital programming and project selection methods, *NCHRP Synthesis 243* found that 70% of agencies responding to that survey applied BCAs, and more than 50% reported using other cost-effectiveness methods. However, the programs or projects to which these methods were applied differed among agencies and did not represent a consistent pattern of use. The tendency was to use benefit cost on major capacity additions, other high-cost projects, and safety projects. Cost-effectiveness methods were used across a wide range of project categories, with no single one standing out nationwide (Neumann 1997).

This study's Scope of Work summarizes the current situation as follows: "There are [U.S.] transportation agencies that are proficient in integrating economic analysis of their investment options into their asset management strategy using a variety of tools and processes. However, other agencies lack the resources, guidance, and understanding to perform such evaluations." Case examples in chapter three describe successful state DOT applications of EEA across a number of decision points in project and program development and delivery.

STUDY APPROACH

The Scope of Work has specified the type and range of investigations to be conducted in this synthesis as follows: The project has identified and described current practices for performing EEA by U.S. state transportation agencies to evaluate highway investment decisions. Information that has been gathered includes the following:

- Current practices in applying EEA in the decision-making process, such as analyses for benefit cost, life-cycle cost, cost-effectiveness, cost-avoidance, and economic aspects of asset management.
- Current guidance on how to perform EEAs correctly and efficiently within the transportation arena.
- The level of the highway system at which such practices are used; for example, in an individual highway project-, corridor-, program-, or network-level of decision making.
- Identification of the stages of planning, programming, project development, and project delivery in which an economic analysis is performed.
- Measures used in assessment; for example, benefit–cost ratio, net present value, return on investment, or other measure.
- How the analysis influences the decision process.
- Who performs the analysis: agency personnel, consultants, or other parties?
- Recent case examples of the use of EEA at various stages of decision making.

Data collection focused on state transportation agencies that perform highway network and/or project-level economic analyses as part of their normal decision-making process. Information was gathered through literature reviews and web searches, including those covering international practice. Input on potential case examples was also solicited from the synthesis topic oversight panel and members of the TRB Transportation Economics Committee (ABE20) and the TRB Asset Management Committee (ABC40). Interviews were conducted with candidate agencies, complemented by additional literature reviews and web searches. Interviews were also conducted with agency representatives knowledgeable of current engineering economic practices, particularly at FHWA. A further effort to identify potential case example candidates consisted of a screening survey. The screening questionnaire was sent to the AASHTO Standing Committee on Highways (SCOH) member in each state, with a copy to that state's AASHTO Research Advisory Committee (RAC) member. A corresponding questionnaire was also sent to the FHWA division office in each state.

This report summarizes the findings of these investigations. It identifies methods and techniques, business processes, and agency resources now being used for EEA. The emphasis is on state DOT practice, although interesting and instructive examples from other agencies have been included. The focus is on innovative, unique, or comprehensive applications of EEA for highway investments specifically, recognizing that corresponding examples exist for other surface transportation modes such as rail and transit. The case examples in chapter three are the focal point of this report. They illustrate not only the application of engineering economic methods to various decisions in highway investment, but also the particular practices used by agencies in building such analyses; for example, compiling data, selecting a discount rate, accounting for risk or uncertainty in estimates, and defining alternatives. As such, they satisfy a majority of study objectives set forth in the Scope of Work. This use of case examples as the primary means of documenting current practice is in contrast to that of many other NCHRP syntheses, which typically provide a nationwide summary of existing practice among a large sample of state DOTs together with a comprehensive explanation of conventional methods, procedures, and analytic tools. The body of literature on EEA is extensive and it would be difficult in a report of this size and scope to treat every relevant topic exhaustively. Instead, brief descriptions of the most important topics with references to other sources have been provided for conventional methods and tools (refer to chapter two). The report also describes work now in progress that may lead to future advances in the state of practice and expanded application of economic methods. Existing gaps in current knowledge have been translated into recommendations for future research.

SYNTHESIS ORGANIZATION

This synthesis report is organized as follows: Chapter two presents information on guidance and methodology related to EEAs, including sources providing national-level guidelines, references to useful texts, a discussion of international usage of these techniques, results of the survey conducted under this synthesis plus survey results completed by others, and discussion of the challenges in implementing EEAs. Chapter three presents a series of case examples illustrating the application of these methods to a range of highway investment decisions. Each case includes agency-level context, relevant data and analytic tools, and roles of economic analysis within business and decision processes. Chapter four discusses the benefits of implementing engineering economic methods, organizational capabilities helpful in promoting wider and more effective use of these methods, and factors instrumental in creating a supportive organizational culture. Chapter five concludes the report. A list of abbreviations and acronyms used in the report precedes the References and Bibliography. Appendix A contains the questionnaire used in the screening survey. Appendix B contains the interview guide used in case example development. Appendix C lists survey participants: state DOTs and FHWA division offices. Appendix D compiles relevant federal laws specifying the use of BCA for highway investments.

CHAPTER TWO

ENGINEERING ECONOMIC ANALYSIS

POLICY AND PROCEDURAL GUIDANCE

There are a number of policy statements and guidelines that govern application of EEAs to highway investments nationwide. There are also research reports that explain methods and procedures available for use. The references are issued primarily by the federal government [e.g., Office of Management and Budget (OMB) and U.S.DOT/FHWA] and national organizations (e.g., AASHTO and NCHRP). Several of these references will also be cited in the case examples in chapter three. Specific state, regional, or local guidance is not included here; however, pertinent references at the state and regional levels will be included as appropriate with each case example in chapter three.

- **Presidential Executive Order 12893, Jan. 26, 1994: Principles for Federal Infrastructure Investments.** This presidential order applies to "federal spending for infrastructure programs," encompassing "direct spending and grants for transportation," water resources, energy, and environmental protection. Among the requirements are the following (*Executive Order 12893* Jan. 26, 1994):
  - A systematic analysis of expected benefits and costs of the investment, including quantitative and qualitative measures.
  - Use of discounted CBA "over the full life cycle of each project."
  - Recognition of potential uncertainty in estimates of the amounts and timing of costs and benefits, and where these costs and benefits are important, use of appropriate quantitative and qualitative risk management techniques.
  - Definition of a comprehensive set of alternatives for evaluation and comparison, including but not limited to "managing demand, repairing facilities, and expanding facilities."
  - A series of recommendations addressing the efficient management of this infrastructure.
  - Consistency with *OMB Circular A-94* (discussed next).
- ***OMB Circular A-94: Guidelines and Discount Rates for Benefit–Cost Analysis of Federal Programs.*** This document was revised in 1992 and includes a recommended discount rate of 7% for constant-dollar BCAs. Appendix C of the *Circular,* which is updated annually, includes rates for cost-effectiveness analyses in which project benefits do not have to be explicitly stated. The implied discount rates using *Circular* Appendix C data are lower; for example, the 30-year real interest rate on Treasury securities is 2.7% (as of Dec. 2009) (*OMB Circular A-94*). Several agencies discussed in the case examples have used these Appendix C data, combined with state-specific considerations, in arriving at a discount rate for their analyses.
- **FHWA *Life-Cycle Cost Analysis Primer.*** This guide provides practical information on properly setting up and performing an LCCA between alternative investments. It covers agency costs and road user costs, discusses elements important to setting up the analysis (e.g., length of analysis period, timing of actions, and expenditure stream diagrams), and describes the computations involved. The *Primer* dispels misconceptions and confusions often held about LCCAs by explaining the difference between remaining service life and salvage value, between an inflation rate and a discount rate, and between economic and financial analyses. It recommends that the analysis be done in constant dollars. The *Primer* closes with a discussion of issues and reservations regarding LCCA, and suggestions on how an agency may deal with them (*Life-Cycle Cost Analysis Primer* Aug. 2002).
- **FHWA *Economic Analysis Primer.*** This guide addresses the broader topic of economic analysis, looking at the role of economic analysis in highway decision making and the benefits of its use, explanations of LCCA and BCA, methods to conduct risk analysis, and EIA. Explanations are included for how to handle inflation and the use of differential inflation in a constant-dollar analysis, the concept of the opportunity cost of money as represented in a discount rate, and the importance of including road user costs in an economic analysis (*Economic Analysis Primer* Aug. 2003).
- ***User Benefit Analysis for Highways.*** This AASHTO document explains methods to compute the benefits to road users, generally categorized as savings in travel-time costs, vehicle operating costs (VOC), and accident costs. The manual describes how to evaluate different highway improvements that affect user benefits, how to analyze user benefits in each of the three components, how to conduct benefit–cost calculations, and applicable software (*User Benefit Analysis* . . . Aug. 2003).
- These sources represent general guidance relevant to highway investments. The case examples in chapter

three will cite additional federal and state laws, guidelines, and research studies applicable to the particular case at hand.
- A compilation of federal laws beyond those cited in the case examples, which call for economic analyses of highway investments, is contained in Appendix D to illustrate the breadth of these requirements for economic analyses.

Other reports of interest include documents by the General Accountability Office (GAO) that have reviewed aspects of highway program management, including use of economic methods; guidance documents by the U.S. Army Corps of Engineers regarding BCA; NCHRP Reports and Syntheses of Highway Practice covering specific topics that call for economic analyses; and FHWA case examples on state, regional, and local transportation agency use of economic methods such as the FHWA Highway Economic Requirements System—State Version (HERS-ST). The federal and national-level agencies and organizations that have been discussed in this section maintain websites with information framing their perspectives on EEA. Please note that the guidance discussed here relates only to requirements for economic analyses. Agencies must also comply with other, non-economic requirements on proposed highway investments; for example, provisions governing environmental protection, mitigation of environmental impacts, and environmental justice, to name a few other areas of policy guidance.

TEXTS ON ENGINEERING ECONOMIC ANALYSIS

A number of texts are available that readers may consult for information on methods, techniques, and parameters used in EEA. These texts provide comprehensive coverage of a wide range of topics and issues. They guide readers in understanding the basics, but also address unique or illustrative problems and situations. These texts have been consulted for particular topics addressed in this chapter, including the equivalence in decision results when the various methods of EEA are correctly applied, and the interpretation of the discount rate. Cited texts are listed in the References at the end of the report. Other texts, which have provided background information, are listed in the Bibliography.

Many of these texts present methods and analyses in large part from a private-sector perspective. Their explanations and interpretations must therefore be adapted to investments in the public realm. Some texts include separate chapters that focus specifically on governmental expenditures for public works; this material would relate more closely to the analysis of highway investments. Topics oriented to the public sector might include, for example, discussion of benefits to the public, problem solutions entailing multiple perspectives, multi-criteria or multi-objective decision making, and decisions under budget constraints. Textbook material could be reviewed together with guidance from highway-specific documents, such as the FHWA primers described in the previous section, to place subjects in a transportation context. One other observation is that the nomenclature in the texts (as well as in other documents, including some of the guidelines discussed in the preceding section) may diverge from the definitions in chapter one. A key example is that the term "interest rate" is used many times to refer to "discount rate." This report will continue to use discount rate as distinct from interest rate to avoid ambiguity between the two, and to maintain a clear distinction between economic and financial analyses.

METHODS

Supporting Investment Decisions

In their textbook on engineering economy, Grant et al. cite several questions that an engineer might raise regarding a potential investment (Grant et al. 1990, p. 4):

- Why do this at all?
- Why do it now?
- Why do it this way?
- Will it pay?

The first three, credited to General John J. Carty, chief engineer of the New York Telephone Company in the early twentieth century, are essentially more detailed considerations leading up to the overarching final question. These questions invoke thought processes that engineers need to go through in determining how to meet an identified need or problem, recognizing that in civil works there are many choices in the type, magnitude, timing, and location of investments. With highway systems as examples, these choices exist within programs (e.g., preservation, mobility, and safety) as well as across them. The structuring of the analytic steps needed to address these questions establishes the foundation of the methods used in EEA. This foundation is reflected in the following concepts by Grant et al. (1990, pp. 5–14), with highway-related examples provided by the synthesis author:

- **Recognizing and Defining Alternatives.** Decisions imply selections among alternatives. For example, highway preservation may benefit from preventive maintenance now or corrective maintenance later. Going further, there are choices among capital versus maintenance actions to preserve existing assets. Capital preservation may entail periodic rehabilitation or less frequent but more expensive reconstruction or replacement. Ranges of alternative investments may likewise be defined, say, for mobility (congestion mitigation) and safety improvements. An economic approach to these choices helps to identify courses of action that provide worthwhile benefits for the appropriate costs incurred, and that avoid "gilt-edging": that is, the tendency to seek a perfect or ideal solution that is excessively costly.

- **The Need to Consider Consequences.** The consequences of highway decisions—costs as well as project impacts, results, or outcomes—have become more familiar to the highway community with the growing importance of performance management and accountability reporting. The consequences of a decision necessarily follow the decision—therefore, EEA necessarily involves projections or forecasts of the future. Although estimates of the future always involve risk or uncertainty, the need to forecast is inherent in many engineering calculations (e.g., pavement design, road capacity design, intersection capacity design, safety projections, and infrastructure deterioration modeling) and tools are available to help with decision making in this context. Later sections of this chapter will deal with risk analysis and identifiable issues in forecasting; several case studies in chapter three illustrate techniques to deal with risk and uncertainty. (Both costs and benefits are treated as consequences, because in many transportation analyses benefits are construed as reductions in costs or costs avoided. Similarly, "negative benefits" or disbenefits affect the analysis in a manner similar to costs.)
- **The Need for a Viewpoint—Consequences to Whom?** In private-sector analyses, the appropriate viewpoint is often that of business owners seeking profit. Public-sector analyses are more complicated—rarely is the intended benefit limited solely to the government agency. (The ability of an agency to perform within its budget is a separate matter—one of many reasons for distinguishing between financial and economic analyses in chapter one.) With respect to transportation, the viewpoint is generally that of the public at large. However, it will be clear in subsequent sections that even this broad perspective is not always sufficient—the "public" comprises stakeholders and constituents who themselves reflect different viewpoints. Certain chapter three case studies illustrate particular aspects; for example, the federal versus the regional perspective in the Critical Facilities case example, maritime versus regional highway conveyance of freight in the same example, and different values of time associated with different road users in the Accelerated Project Delivery case example.
- **The Desirability of Commensurable Measures.** Economic costs and benefits that are all monetized can be compared in a straightforward manner—the challenge is to estimate these as accurately as possible, or at least to be aware of simplifying assumptions. The value of commensurable measures is illustrated in almost all cases in chapter three, but particularly in the Economics-based Tradeoffs example. For some consequences, however, the use of noncommensurable measures is unavoidable (see also the next item).
- **Comparisons of alternatives might consider nonmonetized as well as monetized consequences.** That important consequences of investment decisions may not be able to be monetized or even quantified is recognized in federal policy. Provisions of Executive Order 12893 acknowledge that nonmonetized (or nonmarket) and qualitative benefits may need to be included in an analysis (*Executive Order 12893 . . .* Jan. 26, 1994). All of the case studies in chapter three address cost as a monetized consequence. Although most of them also include monetized benefits, some use other approaches. For example, the Bridge Programming and Permitting case applies a utility function to characterize the health of bridge assets as a measure of benefit; the Safety Programming case shows instances where the frequency of fatal and serious-injury accidents is used as a surrogate for the monetized economic cost of these collisions.
- **Only differences in consequences matter when comparing alternatives.** This principle has several implications:
  - Only the future matters; past investments or "sunk costs" are no longer relevant in decisions on future investments.
  - In situations where discounted benefits streams among all investment options are close in value to one another, a BCA may reduce to a simpler, discounted cost-minimization problem. This situation may occur when policy or practice results in essentially the same performance trend among all candidate investments (a situation that may arise, for example, in pavement preservation).
  - An accurate tally of differences in consequences among candidate investments requires the actual costs (or benefits) associated with each option. Average costs (which often result from simplifying assumptions in management systems) or allocated costs (as computed by cost accounting systems) may lead to incorrect economic conclusions.
- **Separable decisions could be made separately whenever practicable.** Within the highway transportation field this principle often applies to how project alternatives are defined. A proposed project may combine several types of highway improvements that otherwise could be performed separately; for example, renewed pavement surface condition, new safety hardware, mobility enhancements, and improved drainage features. It is preferable to evaluate each project component incrementally and retain only those that pass economic muster ("each tub on its own bottom"), rather than analyzing the entire project in a single step. An economic result for the project as a whole might mask the weak economic performance of one or more components that would not be viable on their own.
- **Criteria for decision making are needed.** Criteria help structure a decision to meet stated policy goals and targets, and to guide a decision maker in dealing with multiple goals and objectives reflecting competing and sometimes contradictory interests. The primary criterion of an economic analysis would relate to making the best use of limited resources. Other criteria can

resolve the need for investments to serve additional needs and purposes such as the following:

- Various aspects of equity: the need to ensure a fair distribution of investments and impacts thereof across the state. Examples might include geographic equity (e.g., maintaining a fair balance of road investments across rural and urban needs); jurisdictional equity [e.g., maintaining a fair balance of road investment distributions among the state DOT or the state highway administration, metropolitan planning organizations (MPOs), rural transportation planning organizations (RTPOs), and tribal nations]; and environmental justice issues that require agencies to avoid actions that would impose disproportionately high adverse impacts on human health or environmental conditions affecting minority populations and low-income populations.
- The need for network continuity and connectivity, ensuring that a reasonable and consistent level of engineering standard and development is maintained along a link or corridor.
- The need to serve nonmarket or qualitative objectives, particularly those required by federal or state law and stated agency policy; for example, neighborhood cohesion, economic opportunity, and environmental protection. (Some of these objectives may be reflected in the equity considerations discussed earlier.)

These criteria can be organized hierarchically or with appropriate threshold values for invocation to provide the intended guidance to decisions. For example, Washington State's pavement type selection process (discussed in chapter four as part of Implementation) applies solely to the primary (i.e., the economic) criterion to type selection if the cost difference between the pavement alternatives is at least 15%. (Other states also use tolerance thresholds: refer to the Pavement Type Selection case in chapter three.) This method ensures that the economic superiority of the selected alternative is robust and not likely to be affected by uncertainties in the estimates. If the cost difference between alternatives is less than 15%, then other, nonmarket or nonquantitative criteria must be considered in selecting the preferred pavement type. Grant et al. (1990) caution, however, that verbal descriptions of advantages and disadvantages be structured properly to avoid a form of "word" power double-counting; that is, where the same basic argument is stated in different ways to make one alternative appear to be vastly superior to another.

- **Even carefully conducted estimates of consequences may turn out to be incorrect.** It was stated earlier that projecting the future is not an exact science, and that tools are available to help a decision maker understand the relative strength or weakness of a prediction of consequences. One approach is the application of secondary criteria relating to uncertainty in estimates of future consequences, as described in the preceding item. Another is the application of risk analysis methods, described in a later section. As the chapter three case examples illustrate, agencies that use EEAs extensively invoke an attitudinal as well as an analytic response to addressing risk and uncertainty in their estimates:
  - Their clear objective is to have economic analysis results that aid their decisions. They resist the temptation to create excuses based on the challenges in performing these analyses perfectly, be they issues of data, assumptions of future conditions and behaviors, or difficulty in identifying all reasonable alternatives to meeting a need or solving a problem.
  - They are willing to devote the time and resources to resolving significant issues of uncertainty or risk. Agency guidelines, analytic tools, review procedures, follow-up studies, re-examination of assumptions, staff training, and website "knowledge resources" are among the steps taken by agencies to ensure the best decisions based on the best information. (Chapter four elaborates on agency implementation of economic methods.)
- **There is a need for a "system viewpoint" as well as one focused on the problem at hand.** This principle relates to possible interactions among a group of decisions and their respective side effects. In a highway system context, for example, the congestion caused by a work zone for a project may cause temporary traffic diversions to other routes. Diversions owing to a single project may not be significant enough to require analysis of its consequences on other routes. However, if multiple projects occur within the region, their combined diversion effects may need to be studied, with implications for the scheduling and perhaps work requirements on affected projects.

Discounted Cash Flow Methods

Computational methods have been developed to perform EEAs according to the principles described earlier. These methods include net present value (NPV), equivalent uniform annual cost (EUAC), BCA (or B/C), and internal rate of return (IRR). Only a brief commentary on these methods is provided in this synthesis, consistent with the study scope outlined in chapter one. The focus of this report is rather on the application of these methods to support highway investment decisions as illustrated in the several case examples in chapter three. The methods are well described in the general engineering–economics literature. They are also described in references providing transportation- and highway-specific guidance. Risk analysis methods are covered in the next section.

Although the four methods listed entail somewhat different data and procedures, they all will yield the same decision when applied correctly (Grant et al. 1990, chapters 4–7).

This synthesis adopts this position, which is based on the following precepts:

- All of the engineering economic methods are based on a LCCA of investment alternatives. The LCCA is a discounted cash flow analysis of monetized cost and benefit streams. The analysis period or analysis horizon, in years, is sufficiently long to capture a reasonable representation of the significant costs and benefits of each alternative through equivalent periods of performance. The four methods identified previously (NPV, EUAC, BCA, IRR) all meet these stipulations. Other methods (such as project payback periods) have their uses in other contexts, but generally do not meet these characteristics of LCCA. (Project payback periods may or may not depend on discounted cash flows; they do not analyze alternatives through equivalent performance periods; and they therefore do not capture the full representation of costs and benefits through a performance period.)
- Net benefits and net costs are used to assess the differences in consequences among alternatives. Both costs and benefits may take on positive or negative values, and bookkeeping conventions could be established to treat the respective quantities consistently and correctly. For example, the consequences of highway investments on passenger and freight travel are measured in road user costs. When comparing alternative investments, reductions in these costs (or avoidance of these costs) are treated as benefits. Conversely, actions that increase road user costs are said to incur disbenefits. Case examples in chapter three involving use of the California DOT's (Caltrans) Cal-B/C model will illustrate how these net-value calculations in tallies of discounted agency and road user costs are interpreted for the economic analysis results.
- In comparing alternative solutions, BCA and IRR analysis are both properly done on an incremental basis. There is considerable literature covering both "simple" B/C or IRR and "incremental" B/C or IRR calculations. If a project is being compared solely with a "No-Build" or "Do Nothing" option, the incremental case reduces to the simple case, and both yield the identical result. The same decision on whether or not the investment is economically justified will also be produced by the NPV and EUAC methods.
- When there are a number of investment alternatives addressing a particular need or problem, however, the proper approach is to conduct the B/C or IRR analysis incrementally. The simple B/C result can be used as a screen: a simple B/C of less than 1.0 will not bear out on an incremental basis either. However, in the general case that is not subject to a budget constraint, a solution with the highest simple B/C may not necessarily be the optimal solution. Rather, the theoretically optimal result is the investment with an incremental B/C exceeding 1.0.

Risk Analysis Methods

"Risk" and "uncertainty" both refer to imperfect information about future consequences. Risk involves an indefinite result, but one whose characteristics are possible to quantify. For example, the time to failure of a signal lamp or roadway luminaire may not be known precisely, but can be estimated statistically from laboratory failure studies. Uncertainty refers to a result that is not known definitely and is difficult to quantify in a practical sense. Analysts often address uncertain consequences through a set of assumptions that define one or more scenarios. For simplicity, both risk and uncertainty are addressed in the literature using what are referred to as "risk analysis" techniques.

One set of risk analysis methods involves varying selected parameter values and assumptions through repeated applications of the economic analysis for each project alternative. The results indicate to what degree the proposed project solutions are affected by this variability. Information technology hardware and software enable hundreds or thousands of analysis cycles to be done economically and efficiently. Different methods that adopt this approach include the following:

- **Bracketed analysis.** If only one or a few parameters are to be tested under different values, analysts may define a minimum, most likely, and maximum value for each, and then obtain three sets of results corresponding to the minimum, most likely, and maximum specifications. The result is a bracketed analysis that indicates the realistically possible range of consequences, minimum to maximum. Analysts may then investigate the economic implications for the preferred solution if future consequences are different from the case that is judged "most likely" today.
- **Sensitivity analysis.** A parameter (or related set of parameters, such as vehicle distribution percentages to express highway traffic composition) is varied across a set of values to assess its effect on the solution. The economic analysis is repeated for each value to determine the effect on project consequences and implications for the preferred project solution.
- **Scenario analysis.** An underlying assumption is varied to represent different possible behaviors or situations; for example, shifts in demographic or market characteristics that affect transportation demand or future changes in the price of critical items such as materials that can affect project costs. These varying assumptions are translated into corresponding sets of parameter values, each of which is tested in the economic analysis to determine the effect on project consequences and the implications for the preferred project solution.
- **Probabilistic analysis.** In lieu of providing a single, deterministic value for each parameter, analysts provide an input probability distribution. The details of this input vary according to the software used, but one approach is to specify the type of probability distribution desired

(e.g., uniform, normal, or beta) and a set of parameter values that define the key characteristics of the selected distribution. For example, a beta distribution can be estimated with minimum, maximum, and most likely values to describe its shape. The probabilistic input data are subjected to a Monte Carlo simulation within the framework of the economic analysis, producing a probabilistic output distribution that describes the range of project consequences and their expected likelihood. Analysts can use this information to assess the implications for the preferred project solution.

- **Option risk; threshold or breakeven analysis.** When a preferred option has been tentatively identified through an economic analysis, this method helps decision makers to understand whether it is the best alternative: that is, how robustly it can withstand the effects of risk and uncertainty. Each element of risk or uncertainty is considered, with the underlying question of how the preferred option is affected by the occurrence of that possibility. A threshold or breakeven analysis can be performed to help decision makers visualize the impact of an uncertain event coming to pass. Each parameter of the problem that might be affected by possible risks or uncertainties is considered in turn. Another way to structure the analysis, particularly if some parameters are not quantifiable, would be to determine what level of project outcomes would be needed to justify the cost of building the project. The threshold is the value of the selected parameter that is needed to establish the tentatively selected option as the best among all alternatives. It is also referred to as the breakeven value because it marks the point where the tentatively selected option becomes more cost-effective than all other alternatives. Although this approach helps to quantify aspects of the problem when risk or uncertainty is present, it still requires judgment by the analyst to determine if the threshold value can be realistically achieved in light of the possible sources of risk or uncertainty (adapted from *Transport Canada Guide to Benefit Cost Analysis* 1994).
- **Economic Factor of Safety.** *NCHRP Report 551* suggests ways in which standard economic methods and criteria can be applied to guard against solutions approaching a threshold of increased risk too closely (paraphrased from Cambridge Systematics Inc. et al. 2006, p. 86):
  – Use available models that show how road user costs (e.g., travel time, VOC, and accident costs) vary with different levels of condition or performance. Examining the slopes of these curves can reveal the performance level at which user costs begin to increase rapidly. Select performance criteria to avoid approaching this point of rapid user cost increase.
  – Make use of the law of diminishing marginal returns to identify the point at which additional investments begin to have a declining degree of impact on improvements in performance—in other words, where the slope of the investment–performance curve begins to level off or decline. Curves relating performance trends to levels of investment can be used for this purpose. Alternately, models can be exercised repeatedly at different levels of available budget to see where diminishing returns begin to appear. Select a level of investment that avoids significantly diminished returns.
  – A corollary to the law of diminishing returns is that caution could be exercised in setting targets that call for 100% achievement of a particular condition or service level, because the benefit–cost ratio associated with achieving the last 1% increment will typically be quite low. For example, setting a target of no structurally deficient bridges could necessitate costly replacement of a bridge that currently is not heavily used and that at most provides a redundant link in the network.

All of the risk methods illustrated in the case examples are of one of these types. There is a second group of risk methods that deal with the decision criterion to be employed (e.g., minimax or maximin solutions and their variants). These methods are not included in the case examples and are not discussed further in this report.

Other Methodological Considerations

Discount Rate

Both an interest rate and a discount rate reflect a time value of money. Whereas an interest rate is a charge for the use of money, the discount rate represents a different concept: an opportunity cost. When dollars in the public sector are invested in Project A, that money is not available for Project B or for any other public or private purpose. The discount rate thus ensures that the return on Project A in terms of benefits to the public is at least as great as the minimum return that could be gained by investing in alternative investment opportunities (Project B or other options, whether public or private). Several reasons to define a nonzero discount rate are as follows (paraphrased from Winfrey 1969, pp. 72–73):

- The investor—the public—has alternative uses of the highway tax money for dividend or profit-returning investments or for immediate satisfactions that are forgone when that money is applied to highway investments. This concept of alternative uses forgone is referred to as the opportunity cost.
- The timing of proposed disbursements (cash flows) will vary with the type of disbursement (e.g., construction expenditures and maintenance expenses). A mathematical discount factor is needed to bring all monetary disbursements throughout the analysis period to an equivalent basis.
- A zero discount rate (which is proposed occasionally) is misleading because it does not weigh the relative desirability of different cash flows over time. It says that a dollar received today would have the same value now as a dollar that is to be received, say, in 10 years would have now.

In Winfrey's view, average interest rates or bond rates are not appropriate discount rates (i.e., the discount rate is not necessarily equal to these interest or bond rates, although the case examples indicate that rates on selected instruments can be part of the *calculation* of discount rates). The cost of financing or borrowing is not the economic cost to people who pay taxes to furnish the debt. They do not reflect the worth of money or the worth of a proposed highway improvement (where the "worth" is interpreted as different from "cost") (Winfrey 1969, p. 76).

A complementary rationale for the use of a discount rate is given by Moavenzadeh and Markow (2007, p. 28):

- A discount rate represents a time value of money—people tend to prefer having a dollar now to a dollar in the future.
- The discount rate reflects the marginal productivity of capital: that is, a dollar's worth of resources today can be invested productively to yield more than a dollar's worth of benefits or outputs in the future.
- The discount rate reflects the opportunity cost of capital, as discussed earlier.

According to *OMB Circular A-94,* the current discount rate for BCAs (as of Dec. 2009, the period in which this report was prepared) is 7%. Additional data are provided in Appendix C of the *Circular* and updated annually; these values are intended for cost-effectiveness analyses. These data provide real Treasury borrowing rates on marketable securities; analysts could select the rate for securities with a maturity comparable to the period of their analysis. For projects with an analysis period of 20 to 30 years or longer, these Appendix C rates are 4.4% to 4.5%, considerably lower than the 7% recommended for BCAs. As the case examples in chapter three will show, several agencies use Appendix C data as part of their basis for determining their respective real discount rates, resulting in an overall range across all the case examples of 3% to 4% at the lower bound and 7% at the upper bound. This range is consistent with findings of other sources; for example, 4% to 7% for safety BCAs (Hanley 2004), and 2% to 4% cited by FHWA as an appropriate real discount rate given recent trends (Stephanos Nov. 13, 2008: refer to the Pavement Type Selection example in chapter three). The case examples also illustrate specific methods that agencies use to derive values of their discount rate. It is well understood that the selected discount rate can affect the results of an economic analysis:

- Higher discount rates reduce the present value of future costs and benefits more rapidly;
- Lower discount rates reduce the present value of future costs and benefits less rapidly;
- A zero discount rate does not reduce the present value of future costs and benefits at all (that the future costs and benefits have the same present value as current costs and benefits in this case is the reason that a zero discount rate is opposed by Winfrey in the earlier comment).

A sensitivity analysis can reveal to what degree the results of the analysis vary with the choice of a particular rate. Even the relatively modest discount rates within the range used in the case examples can effectively suppress the effects of costs and benefits several decades in the future. For example, with a 5% discount rate, future value declines to 50% of current value in 15 years, to 10% of current value in about 50 years, and to 1% of current value in about 95 years. The equivalent time frames for the same percentage declines in future value given a 7% discount rate are approximately 10 years, 35 years, and 65 years. This effect becomes important with highway facilities that have very long lives (e.g., major bridges) or strategies with very long-term consequences (e.g., investments to address climate change, with benefits intended for future generations). The use of discounted cash flow analysis in these cases may present an analytical impediment to evaluating fairly those investments that yield consequences in the distant future. An approach to deal with this problem for very long analysis periods (as encountered in sustainability analyses with multi-generational benefits) entails treating the proposed investment in two phases: the first, to examine long-term sustainability with the objective of conceiving and shaping project candidates that are specifically designed to satisfy these long-term goals; the second, to conduct traditional economic project-evaluation analyses (discounted cash-flow analyses as well as risk analyses) for those alternatives appropriate to long-term perspectives that are identified in phase one (Moavenzadeh and Markow 2007, pp. 29–30).

Data, Forecasting, and Assumptions

Another area of EEAs considered to be problematic by some potential users is the uncertainty of data, forecasting, and assumptions that describe future performance and consequences of alternatives. The key concern is that by getting these factors wrong, the resulting decision may also be wrong; the value of the economic analysis among those holding these concerns is thus called into question. Certain comments from the screening survey and the challenges in applying economic methods described by FHWA and GAO, which will be presented later in this chapter, provide examples of these perceptions. There is a degree of objective validity to these concerns.

For example, research has demonstrated risk, inaccuracy, and bias in forecasts of transportation demand. Transportation demand is an important determinant of the benefits of transportation projects and of revenue projections for toll facilities. In a statistically significant study of traffic forecasts for transportation infrastructure projects among 14 countries, Flyvbjerg et al. (2005) found that 50% of 183 completed road projects in these 14 countries had actual traffic varying by more than ±20% of forecasted volumes, with 25% of the projects having actual traffic volumes varying by more than ±40% of forecasted volumes. When highway projects were compared with rail projects, the evidence of a greater bias in the rail forecasts was evident, owing to a greater degree of competition for rail funding and "deliberately slanted forecasts" that provided optimistic projections of ridership and revenues, accompanied by underestimation of costs (Flyvbjerg et al. 2005, pp. 138–140). A similar phenomenon of optimistic bias within a varied history of forecast results has been reported in *NCHRP Synthesis 364* for estimates of toll road demand and revenue on projects in the United States (Kriger et al. 2006). Flyvbjerg et al. recommend two paths by which the reliability and accuracy of forecasts can be improved, depending on the underlying motivation at work. If the motivation is to develop more accurate forecasts, they recommend a newer methodology, reference class forecasting (Flyvbjerg et al. 2005, pp. 140–142). If the underlying motivation is to bias results (typically to favor proceeding with the project), the solution is to impose checks and balances on the forecasting process, accompanied by mechanisms that promote greater transparency in assumptions, methods, data, and accountability regarding the analytic results. These mechanisms might include the following examples: to subject the forecast to benchmarking, independent peer review, public disclosure, and engagement by stakeholders and citizens at hearings, citizen juries, and similar forums; and to present the analysis at professional meetings that subject the methods, data, assumptions, and findings to peer review and comment (Flyvbjerg et al. 2005, pp. 142–143).

There is no reason to presume that forecasts for engineering economic studies are immune from these problems. However, the following points also could be noted:

- Forecasting is involved in many engineering applications. Forecasts of travel demand, resulting traffic volume and composition, and vehicle and driver characteristics are central to planning and design of new roads as well as to analyses of projects to improve mobility, safety, and preservation of the existing system. Although errors in these forecasts can result in incorrect estimates of basic highway elements such as the need for the project itself, the proposed number of travel lanes, pavement thicknesses, traffic operations features, and safety appurtenances, such concerns do not remove the need to perform these kinds of analyses. Rather, the solution may lie in the types of recommendations posed by Flyvbjerg et al. (2005).
- Risk analysis methods that were described earlier enable analysts to assess the implications of data estimating and forecasting errors, as well as potentially erroneous assumptions. These methods can help agency staff to craft more flexible or robust solutions that minimize adverse consequences resulting from risk and uncertainty.
- Refer also to the discussion of ex-post analyses in chapter four, which discuss forecasting bias in appraisal estimates and how a disciplined program of ex-post analyses can result in more accurate forecasted estimates in the future.

Compelling illustrations of how several agencies put these ideas into practice across a wide range of highway investment decisions are presented in the case examples in chapter three. Agencies that successfully apply EEAs across their business processes strive to develop and maintain the tools and capabilities to perform these analyses effectively, but in a practical, commonsense way. These tools and capabilities include effective guidance and executive support, staff knowledge and skills, financial and administrative resources, methods incorporated in business processes, data collection and analysis, information technology systems, and supporting institutional relationships with other organizations. The perspective is fundamentally one of incorporating economic analyses within the normal, routine business processes that an agency must perform to do its job effectively, rather than one of viewing economic analyses as additional, somewhat isolated, adjuncts to other activities. Beyond marshaling the resources, processes, and tools to perform these analyses, the agencies highlighted in chapter three also promote an organizational culture that supports EEAs in two ways: a *demand* for the information that these economic studies can provide, and a *supply* of talent, time, and dollars needed to produce this information. These aspects of organizational culture and the tangible and intangible benefits of performing EEAs are revisited in chapter four.

Network and Locational Aspects

Highway transportation is a network-based activity. It is not surprising, therefore, that several case examples make explicit use of network and locational information. How they do this depends on the type and purpose of the highway need to be addressed and the capabilities of the analytic systems available to the performing agency. For purposes of this discussion, "network" information implies spatial data that enable a management system or model to build a topographically correct virtual network mirroring the physical highway system: that is, descriptions of links and nodes. "Locational" information refers to spatial data that describe where a highway segment or point structure is located; for example, by route-milepost, longitude-latitude, grid system, or similar device—but does not include the link-node relationships that describe a fully formed network (e.g., descriptions of connections among links at a node are not provided). Both locational and network information enable use of a geographic information system (GIS) for mapping and locating events on the highway system, but only network information (as used in this report) enables accurate modeling of the flows of people, goods, and vehicles throughout the highway system as needed, for example, in travel demand modeling. This difference between locational and network information is one of the reasons for distinguishing between "network-level" and "program-level" analyses in the Study Approach in chapter one. Although both categories relate to a highway system, the network level implies network information about the system; the program level allows for locational information, but does not imply network information.

With these distinctions, the case examples in chapter three fall into the following categories:

- Spatial relationships are not critical for certain cases; therefore, locational or network information is optional; for example, for GIS mapping, or if the analytic system already includes locational or network descriptions for other purposes. Pavement type selection is a case example that does not require spatial information other than to locate and identify the particular highway segment.
- Asset preservation also falls into this category. Pavement preservation studies may benefit from locational information in presentations involving GIS, for example, but this requirement is not a general one (apart from GIS use, road segment identification may present the primary need for locational data). The economic analysis in the Pontis™ bridge management system addresses the road user cost of traffic detours resulting from bridge load or clearance restrictions, a network-level effect. All of the information needed to compute detour costs is included as part of the bridge description, and therefore does not require any supporting network-level capability (Cambridge Systematics, Inc. 2005). Other types of highway assets vary in the spatial information that is gathered and available for analysis. Some agencies may locate safety and roadside hardware fairly precisely through global positioning system technology as part of field data collection; other agencies may not maintain any inventory information at all for these types of assets (Markow 2007). The scheduling of multiple preservation projects in an area may require a network-level study of work-zone congestion effects to avoid gridlock. Such studies would require a network model, but such models are typically external to the systems analyzing the preservation strategy on each highway segment.
- The emergence of systematic, low-cost safety improvement programs in several states has highlighted the effective use of locational data to diagnose the underlying causes of clusters of crash locations, and to propose effective, low-cost treatments. Refer to the Safety Programming case example for an illustration of this capability and economic studies before construction and after construction to validate the proposed solution (median rumble strips).
- Some engineering economic studies engage network-level effects directly, and a network model (or an economic analysis model linked to the outputs of a network model) must be used. The Critical Interstate Facilities case example in chapter three illustrates such an application. The consultant to the Port Authority of New York and New Jersey applied the Interstate Network Analysis model to derive the transportation economic benefit of each of the Port Authority's Interstate crossings between New York and New Jersey. Although other case examples in chapter three involving Caltrans make use of the Cal-B/C BCA, none of these examples entails a network-level analysis. The Cal-B/C software is capable, however, of accepting travel-flow information from an external travel demand model and applying it within what is referred to as an extended corridor analysis. With this capability, Cal-B/C is able to analyze interchange projects, bypass projects, and passing-lane projects, in addition to those that do not require a network capability (Booz-Allen & Hamilton Inc. et al. 1999).
- These comments are based largely on the practices reflected in the case examples in chapter three. A similar breakout of different needs for, and uses of, locational and spatial information is given in the documentation of the Cal-B/C model. This documentation notes that BCAs typically apply one of the following approaches to deal with network effects (Booz-Allen & Hamilton Inc. et al. 1999):
  - Route-based approach: project benefits beyond the immediate project area are ignored.
  - Extended corridor approach: standard assumptions are used to approximate project impacts beyond the immediate project area.
  - Network-based approach: project benefits are estimated using the output of a regional planning model.

  This source notes that in certain situations it may be appropriate to employ a route-based approach and ignore any off-route benefits as negligible. These cases arise, for example, with route alignment improvements and resurfacing projects, or in rural areas with a limited network such that there are few alternative paths to a given route, making off-route project impacts unlikely.
- It could also be pointed out that network-based travel demand models are themselves subject to forecasting limitations, adding to the issues discussed earlier; specifically, methodological weaknesses and obsolescence in the face of demands for newer types of policy analyses. The four-step travel demand model is not inherently behavioral in nature, and therefore may not accurately capture road users' responses to the types of policy initiatives now being explored by transportation agencies and political bodies. Furthermore, the models more suitably represent aggregate, corridor-level travel behavior, but begin to break down when more disaggregate, individual-level responses must be predicted. The latter requirements would be needed, for example, in estimating the time chosen for travel, individual responses to policies such as congestion pricing and telecommuting initiatives, nonmotorized travel, and freight and commercial vehicle movements. Recommendations include development of new travel demand models, together with organizational and institutional changes among affected governmental bodies: MPOs, state DOTs, the federal government, and intergovernmental relationships (*Metropolitan Travel Forecasting* . . . 2007). This topic is recommended for research in chapter five.

CHALLENGES TO WIDER U.S. APPLICATION OF ECONOMIC METHODS

Government Accountability Office Findings

Although the guidance documents listed at the beginning of this chapter identify the advantages of using EEAs and encourage wider application, practical experience raises a number of concerns that challenge this effort. Three studies by GAO examine economic methods used to analyze highway investments. The reports distill a number of concerns about shortcomings in these methods.

One study considered the use of BCA in transportation planning (*Surface Transportation* . . . June 2004), with concerns summarized as follows:

- BCA tallies net benefits in the aggregate, without regard to the equity of the distribution of these benefits.
- Although impacts such as travel time saved, reductions in emissions, and reductions in accident fatalities and injuries can be monetized, not all researchers may agree on these valuations of impacts. (This topic will be revisited in chapter four, following presentation of the case examples.)
- The way in which projects are scoped may affect results—examples were provided relating to grouping of independent projects, where not all might survive a BCA individually, and how to account correctly for interactions between complementary projects, where benefits of each project individually might underestimate the total benefit of the projects collectively if they were coordinated.
- A BCA that considers impacts in several areas creates the need to forecast data in these areas, a task subject to uncertainty.

The second GAO study considered a range of possible problems with BCA of highway and transit investments (*Highway and Transit* . . . Jan. 2005). Following are examples of the issues that were identified:

- The inability of models to accurately predict key effects of transportation investments; for example, changes in land use, driver behavior, or diversion to alternate routes or modes. This problem is aggravated by the diverse set of models employed by local agencies.
- Lack of complete, accurate data may distort forecasts and lead to erroneous results. Surveys of travel demand are becoming harder to fund and to conduct.
- Certain benefits are double-counted; certain expenditures are counted as benefits. Sometimes future benefits are cited at their nominal value, not discounted to present value. The avoided cost of another project may be counted as a benefit of the project that is being analyzed.
- The definition of alternatives may miss viable options in the current mode or in other modes (e.g., failure to compare a highway project with a transit option).
- Benefits that are difficult to quantify may be overlooked or eliminated from the analysis.

This report also included a survey of state DOTs conducted in October 2004, which asked their opinions on factors of great or very great importance in the decision to recommend a highway project. The higher-ranked factors in descending order were political support/public opinion, availability of state funds or federal matching funds, cost-effectiveness, and distribution of impacts across social groups. Economic impacts, ratio of benefits to costs, and availability of local funds were among the lower-ranked factors. The result of a BCA fared better in a similar survey of transit agencies.

A third GAO study considered the BCAs used to evaluate policies encouraging shifts of passenger and freight traffic to rail. Two federal grant programs—the TIGER grants, discussed in more detail in the next section, and the High-Speed Intercity Passenger Rail program—included benefit–cost assessments that, in GAO's findings, "were generally not comprehensive." The quantification and monetization of benefits "varied widely" among the applications submitted. Selected applications that were examined in more detail by GAO for the most part failed to provide information that is recommended in federal guidelines for economic analyses of public works investments (refer to sections at the beginning of this chapter summarizing guidance documents); for example, information concerning risk and uncertainty, data limitations, and assumptions inherent in the methodology. Grant applicants, industry experts, and U.S.DOT officials who were interviewed by GAO pointed out additional challenges: short time periods in which to prepare the economic assessments; lack of access to, or poor quality of, needed data; and lack of standardized values for monetizing certain benefits. Although benefit–cost was one of the stipulated criteria for evaluating the TIGER and the high-speed rail grant applications, these problems limited the usefulness of the economic information provided by the applicants.

Federal Highway Administration Findings

In 2009, FHWA had the opportunity to review EEAs submitted by transportation agencies competing for TIGER grants under the American Recovery and Reinvestment Act of 2009 (ARRA, P.L. 111-5, Feb. 17, 2009). The analyses were mandated by law; the TIGER grant application process demonstrated that state DOTs will perform economic analyses if they are required to do so. Review teams at the federal level included economists from the Office of the Secretary, U.S.DOT and from the modal administrations. There were positive aspects of the review; for example, the demonstration that BCAs are not that difficult, that no modal bias was evident, and that a good economic analysis imposes rigor and discipline, thereby reinforcing the project assessment based on policy criteria. However, a number of common errors were evident in the submittals (Timothy 2010):

- Incorrect treatment of some economic development and local construction impacts as project benefits.
- Improper accounting of project costs.
- Unrealistic base cases and project lifetimes.
- Incorrect treatment of discounting and inflation.
- Incorrectly treating initial-year or design-year numbers as a stream of constant annual amounts.
- Incorrectly estimating safety benefits.

The resulting conclusions by the TIGER grant reviewers were the following:

- A wide disparity in the depth and quality of BCAs.
- Insufficient information on expected project outcomes, accompanied by inadequately supported assertions of project benefits.

The FHWA noted the following observations and lessons learned:

- In future applications of this type, clearer guidance on input values and expectations for the quality and documentation of project benefits and costs will be needed.
- The choice of a discount rate did matter in the exercise.
- Models can both illuminate and obscure outcomes.
- There is a need for research on nonuser benefits and nontraditional impacts of transportation investments.
- The distribution of benefits may need to be better understood; for example, public versus private; local versus national; and by income levels/population groups.

INTERNATIONAL EXPERIENCE

World Road Association

The World Road Association (WRA) conducted a comprehensive review of economic evaluation methods for road projects in member countries as of 2002 (*Economic Evaluation Methods* . . . 2004). Countries included Australia, Canada, Czech Republic, Denmark, France, Germany, Hungary, Japan, Mexico, the Netherlands, New Zealand, Norway, Portugal, South Africa, Sweden, Switzerland, the United Kingdom, and the United States. Methods of economic analysis and evaluation that were included in the review were as follows:

- CBA (equivalent to BCA).
- Cost-effectiveness analysis (e.g., used in cases with nonmonetized benefits).
- Multi-criteria analysis (equivalent to a multi-objective analysis).
- Risk-benefit analysis (similar to CBA, but with explicit allowance for risk).
- Environmental impact assessment (EIA) (various forms of this analysis, sometimes incorporating results of a CBA).
- Some countries also use LCCA to analyze and select certain components of the project; for example, pavement type.

Results of the WRA's survey showed that all 18 countries use BCA, or benefit–cost analysis (CBA), for at least some projects or some components of their analyses. CBA is often combined with multi-objective analyses (multi-criteria analysis), but in different ways and for different types of projects among member countries. BCA may also be combined with other methods, including EIA, computation of socioeconomic benefits, and input–output analyses. In terms of the range of impacts considered:

- Most countries include monetized values of travel time, vehicle operation, and accidents.
- Environmental impacts are monetized by several nations, particularly for noise and air quality effects.

Measures of economic results reported in the WRA study were generally the same as those used in the United States; that is, net present value, benefit–cost ratio, and IRR (although problems can arise with this approach, consistent with discussions of this method in many texts). The one measure that differed from U.S. practice was the First Year Rate of Return, which is used in three countries. First Year Rate of Return is defined as the project benefit in the first full year following completion of construction divided by the project costs over the evaluation period. Thresholds of project acceptability using this metric varied from "greater than 12 percent" to "greater than 35 percent."

European Commission Guide

The European Commission (EC) has published a guide to CBA that is intended for European national and regional authorities investing in the transportation, other civil and industrial infrastructure, and environmental sectors (*Guide to Cost-Benefit Analysis* . . . 2008). The EC *Guide* describes CBA as "applied social science," which "is not an exact discipline":

> It is based largely on approximations, working hypotheses and shortcuts because of lack of data or because of constraints on the resources of evaluators. It needs intuition and not just data crunching and should be based on the right incentives for the evaluators to do their job in the most independent and honest environment. *Source: Guide to Cost-Benefit Analysis* . . . p. 15.

It is important that this wording not be misconstrued as implying a simplistic or informal process lacking in diligent research, data gathering, and quantification. The examples developed in the EC *Guide* demonstrate knowledge of theoretical economics principles, engineering know-how, and a rigorous computational approach.

Although the mechanics of CBA in the European context are similar to methods in the United States, the scope of the

EC *Guide* and the recommended use of economic analysis within the project life cycle differ from the U.S. examples provided in this synthesis. The EC *Guide* is more comprehensive in scope than comparable U.S. publications, encompassing the following:

- Multimodal transportation infrastructure, covering investments in surface transportation networks (road and rail are illustrated in the EC *Guide*'s examples); high-speed rail in Europe; and ports, airports, and intermodal facilities.
- Environmental infrastructure investments in water supply and sanitation, waste treatment, and natural risk prevention (mainly floods and fires).
- Productive industrial investments; energy infrastructure investments including energy transport and transmission, distribution, and renewable energy facilities; and telecommunications infrastructure.
- Investments in other sectors including educational and training infrastructure; hospitals and other health-related infrastructure; forests and parks; and industrial zones and technological parks.

The economic analysis called for in the EC *Guide* diverges from the applications described in this synthesis in the following respects:

- The CBAs in the EC *Guide* are envisioned to occur early in the project life cycle; for example, in the pre-feasibility stage. In contrast, the examples in this synthesis occur throughout the project life cycle, as discussed in chapter one.
- Investments addressed by the EC *Guide* are analyzed generally through a 20-year period. Several chapter three examples use analysis periods of longer than 20 years.

The process of project appraisal, of which EEA is a part, includes the following steps in the EC *Guide:*

- Identification of project objectives and the socio-economic and European national context in which the project will occur.
- Project definition, which may entail civil works, actions, or services, similar to the use of "project" adopted in chapter one of this synthesis. Definition might also specify the perspective to be represented in the appraisal; for example, local, regional, or national (refer to the Critical Interstate Facilities case in chapter three for an illustration of this concept). Indirect benefits in secondary markets would not be included in the economic analysis unless covered by appropriate shadow prices or wages (this point corresponds to the exclusion of economic impacts from this study in chapter one).
- Feasibility and option analysis, which entail identification of options or alternatives and an analysis of their feasibility to test which options can potentially meet the objectives of the project. Examples of different options to be considered for transportation projects include alternative routes, variations in the timing of construction, and different transportation technologies.
- Financial analysis includes items such as investment costs, operating costs and revenues, sources of financing, financial sustainability, and financial returns.
- Economic analysis includes rationalization of costs (i.e., corrections of price or cost distortions to their true values), monetization of nonmarket costs and consequences (including externalities such as environmental pollution), careful consideration of indirect or secondary-market effects (e.g., economic development impacts) to avoid double-counting of benefits, selection of a social discount rate, and calculation of economic performance indicators (e.g., economic net present value, economic IRR, and benefit–cost ratio).
- Risk assessment techniques, including sensitivity analysis, probabilistic distributions for critical variables, descriptions of analysis techniques, assessment of acceptable levels of risk, and risk prevention.
- Other project evaluation approaches and topics are also covered, including cost-effectiveness analysis, multi-criteria analysis, and EIA (more of a macro-economic study, whereas CBA is essentially a micro-economic analysis). EIAs are rare, typically done for mega-projects that are very large in relation to the economy.

The EC *Guide* includes one case study related to road transport: the construction of a new intercity highway to accommodate rapid traffic growth and relieve congestion on an existing link. Two options for the new highway are considered: a toll road and a non-tolled road. The analysis is structured to reflect two sources of traffic for the new highway: diverted traffic from the existing road and generated traffic that did not exist before. The percentage of traffic induced to switch from the existing highway to the new road is price-elastic, with the price comprising the perceived VOC, including the toll on the toll–highway option. Thus, the benefits provided by the new highway will vary between the tolled and the non-tolled options, because fewer vehicles divert to the toll highway because of its higher perceived cost. Because shifts in demand for the new facility will occur as well as changes in the perceived price of transport, the benefit measures used in the EC *Guide* case study include a calculation of consumer's surplus. (Construction of a new highway is not included in any of the case examples in chapter three, so no comparison of methods is available in this synthesis for this category of project.)

The EC *Guide* includes 10 annexes providing additional information on topics such as selection of a discount rate, project performance indicators, evaluation of projects to be performed by public–private partnerships, and risk assessment.

Transport Canada Guide

Overview of Guide

Transport Canada has published a guide on BCA (*Guide to Benefit–Cost Analysis* . . . 1994). Compared with the EC *Guide,* it is focused specifically on transportation and on BCA as the sole analytic method of interest. The specific economic criterion used is the NPV. The *Guide* aims to be a practical source of information to transportation analysts and a framework within which transportation projects of diverse characteristics can be addressed under a common set of principles, methods, and information. Transportation is treated as multimodal, encompassing surface, air, and marine examples, and with shifts between modes part of the consideration of alternatives. The value of an economic analysis is that "all of the important effects of investment choices can be made visible and, to the extent possible, quantified; it is a key tool in the quest for value for money" (*Guide to Benefit–Cost Analysis . . .,* p. 2). The *Guide* treats the elements of a proper BCA in detail, including illustrations with realistic examples but avoiding a "cookbook" approach. Although its focus is on the practical, it occasionally explains the theoretical rationale for a particular step. It is organized around the benefit–cost methodology:

- **Part I—The Evaluation Framework:** addresses the identification of options for analysis, including the base case, and how to establish a common framework for assessing competing options.
- **Part II—Measurement of Costs, Benefits, and Other Effects:** includes the following:
  - Costing principles, the identification of project costs for different phases (planning, construction/development, operation, post-forecast), and LCCA.
  - Benefits and other effects, including measurement principles (basis used is willingness to pay), and transportation benefits in several categories that are discussed in more detail here.
  - Discounting, including the recommended treatment of nominal and constant dollar projections, the rationale for discounting (including the "dollar more valuable now than later" and the opportunity-cost concepts discussed earlier), the recommended value of discount rate (a 10% real rate is stipulated, with sensitivity analyses to be conducted for 7.5% and 12.5%—more on these values later), and discounting conventions.

  Part III—Analysis and Presentation: discusses the evaluation of options, dealing with uncertainty, cost-based comparisons to deal with nonquantifiable impacts, presentation of results, and guidelines for structuring a BCA report for Transport Canada.

  Part IV—Final Summary: provides a bulleted list of items summarizing the entire process of benefit–cost assessment of a project, together with suggested considerations at each step.

Categories of Transportation Benefits

The categories of transportation benefits considered in the Transport Canada *Guide* are broader than those typically identified in U.S. analyses. Overlap between practices in the two countries regarding highway projects occurs in safety benefits and selected transportation efficiency (or mobility) benefits; for example, passenger and cargo travel-time savings, congestion mitigation, and VOC savings. The *Guide* includes a number of suggestions for estimating these quantities; for example, values of passenger time for different system users and for adults versus children, values of travel time for cargo, and methods to estimate avoided costs of collisions for safety benefits. Benefits to non-Canadians are treated as a matter of expected reciprocity and are computed in the same way as benefits to any other passengers. What the *Guide* labels as transitional effects are essentially disruptive impacts to motorists and others resulting from project construction. The *Guide* also cautions that economic impacts representing "multiplier effects" of a project would be excluded from a benefit–cost assessment, which is consistent with the guideline for this synthesis set forth in chapter one.

The *Guide* includes other categories of benefits that are not always found in U.S. highway-related analyses, again recognizing that the Transport Canada *Guide* applies to several transportation modes. These categories include:

- **Small travel-time savings:** This category is that subset of passenger travel-time savings that represents a few minutes per trip. The issue arises because it is not clear whether these small increments of time should be valued proportionally to larger travel-time savings (e.g., so that one minute saved equals 1/60th of hourly savings) or whether small time intervals that fall below some threshold might be valued less than proportionally because they are too small to be used productively elsewhere. The recommended approach is to compute the cumulative small time savings (e.g., the sum of all savings of 5 minutes or less) and value them proportionally to larger savings, but to isolate them from the NPV analysis. In this way they are reserved for separate consideration by management.
- **Generated traffic.** Benefits to generated traffic are taken as less than those to existing traffic. A factor of one-half is recommended as the multiplier.
- **Diverted traffic.** Treatment of benefits to traffic that diverts to a newly constructed facility or service depends on context; that is, what other transport services are available. The *Guide*'s recommendation is for analysts to contact Transport Canada's Economic Evaluation Branch for advice on this point if applicable.
- **Productivity gains.** These are considered for those projects that improve the productivity of government operations. Productivity gains due to a project or other investment (as in training) may result when (1) the same service can now be provided at less cost, (2) for a given

cost the level of service is now higher, or (3) a combination of these two situations. The range of projects that can yield productivity gains is large, encompassing examples such as new air traffic control systems, new management systems and other information technology applications, installation of training simulators, the aforementioned improvement in training programs, and improved communications.

- **Environmental effects.** These are discussed in terms of air, water, and noise pollution; degradation of the natural environment and of habitats; loss of amenities such as access to parkland; and disposal of contaminated soil. As the *Guide* acknowledges, however, identifying environmental impacts is one thing, but measuring or quantifying them is another; and information regarding the values that Canadians place on environmental protection is uncertain and subjective. The *Guide* offers brief, general advice on how to address each of the environmental impacts listed earlier.

Discount Rate

The *Guide* includes a brief commentary on the 10% real discount rate called for by the Canadian Treasury Board. The *Guide* acknowledges that some have proposed a reduction in the 10% rate when there are future benefits and other impacts that call for significant judgment in assigning a monetary value; for example, the avoided cost of fatal and injury-causing collisions, and the avoided cost of environmental damage. The issue is posed as one of intergenerational equity, with some feeling that a 10% discount rate gives too little weight to the interests of future generations. Pending further consideration of the issue, the *Guide* continues to recommend the 10% discount rate for all projects and all categories of costs, benefits, and other impacts.

Other International Sources

Other international sources will be cited in the chapter three case examples (e.g., papers on highway safety) and in chapter four regarding implementation issues, particularly the link between EEAs and performance management and accountability.

SCREENING SURVEY

Motivation and Purpose: Screening Device

Case examples illustrating management applications of EEA are at the core of this synthesis. A screening survey was created as part of the process to identify potential candidates. Although NCHRP synthesis surveys are typically designed to develop a statistical description of current U.S. highway practice, that objective was not part of this screening survey. The primary objective of the screening survey was to increase the chances of identifying good prospects for the case examples, complementing the other efforts described in chapter one (interviews with topic panel members and other experts, committee presentations, and information gained from the literature reviews). Overall, all of these efforts converged on a select number of agencies with comprehensive, well-developed capabilities to perform and apply EEAs. Selection of the agencies whose practices are described in chapter three was made solely on their merit in meeting the study objectives and on their willingness to provide the information needed to develop the case descriptions. “Meeting study objectives” referred to a desire to present cases representing a variety of program areas (e.g., preservation, mobility, and safety), stages of the decision process (e.g., planning and programming), and levels of the system analyzed (e.g., link or project, corridor, program, and network), consistent with the scope of work discussed in chapter one.

Distribution

To ensure the widest possible response within the brief time allocated to the survey, copies of the questionnaire were sent to multiple recipients within each state. The screening survey was distributed as follows.

For state DOTs, questionnaires were sent to the respective members of the AASHTO SCOH, with copies to each state’s RAC member. Copies were also sent to the FHWA division office in each state. Again, the survey was intended primarily as a screening device to identify agencies with information and experience that warranted additional investigation, and which might serve as additional case examples. The survey did not attempt to develop statistical information on the use of EEA nationwide, because past research had already indicated that this use was limited. The questionnaire was purposely kept brief in an attempt to gain quick turnaround and encourage increased response. The survey questions reflected the requirements of the synthesis scope of work, as listed here. A copy of the screening questionnaire is reproduced in Appendix A and asked for the following information:

- Whether the agency uses engineering economic methods at all in its decisions on highway investment.
- For those agencies that do use such methods, to check-off where such methods are used, identifying the following:
  - The highway investment programs for which the methods are used; for example, pavements, bridges, capacity addition, and safety;
  - The stage of the program life cycle for which the methods are used; for example, planning, programming, project design and development; and
  - The level within the transportation system or program for which the methods are used; for example, individual project, corridor, program, network, and cross-program tradeoffs.

- Whether this information is used by the agency's chief executive office in considering decisions on highway investment.
- For those agencies that do not employ economic analyses in their decision making, the reasons for their reservations about economic methods and information.

Twenty-three states provided responses; 17 completed questionnaires came from DOTs; eight, from division offices. In two states, both the DOT and the FHWA division office reported results; the two responses in each state were consolidated and tallied as a single state response. Twenty of the 23 responding states reported that they do use EEAs, whereas 3 states reported not using economic analyses. Written comments by respondents indicated that "using economic analyses" was interpreted as "routinely applying these techniques." Representatives of some state DOTs or FHWA division offices reported that although their state DOT did use economic methods in special situations, they nonetheless described the agency as "not using these methods." The tally of survey results presented here is based directly on the submitted questionnaire responses, with no attempt at further interpretation. Only the 20 states that reported affirmatively their use of economic methods are included in the tally of results.

Results

Key Findings

The use of EEAs by the 20 positively responding states is presented in Tables 3 and 4. Table 3 shows the distribution by stage of decision making for each investment program; Table 4, the distribution by level of highway system at which analyses are performed for each investment program. The last column in each table indicates the number of states that made any use of economic analysis whatsoever for the indicated investment program in that row. These rightmost column entries are identical between the two tables, which would be the expected result. Although entries in each column are summed at the bottom of each table, row entries are not, because these sums would not be meaningful; that is, an agency may use economic analyses at more than one decision stage, and at more than one level of the highway system.

Key findings are as follows:

- EEAs are most widely used in DOTs' pavements and structures programs, corresponding to the wide use of pavement and bridge management systems as well as pavement-type selection procedures. Significant use is also reported in safety programs, a result consistent with nationwide practice reported by Hanley (2004), and in urban mobility programs [which include major capacity projects and Intelligent Transportation System (ITS) projects], a result consistent with earlier findings by Neumann (1997) and with the growing interest in ITS analyses (refer to chapter four).
- Tables 3 and 4 indicate that the greatest use of EEA occurs at the project level, supporting project design and development. The next highest tier of uses in the program development cycle is for planning and programming, which are done at a program level. These statements are generally true for all individual programs surveyed, as well as cumulatively.

Respondents' Comments on Specific Applications

The questionnaire solicited open-ended comments about particular areas where economic analysis is used by reporting agencies, based on items suggested by the scope of work. Agencies highlighted more specific purposes of their economic analyses as follows:

- A BCA for ITS planning and programming.
- A LCCA for material selection as part of the state's pavement type selection. This is done as policy for projects meeting certain scope or budget requirements, as well as other locations when is appropriate.
- A benefit–cost approach in the state's pavement system preservation program for the budget allocation plan, as well as the project location and treatment selection.
- LCCA on larger projects when considering alternatives and more routinely in pavement treatment selection.
- One state DOT noted that its Value Engineering (VE) Bureau at times gets involved in bid evaluation, when requested in special cases, to determine if bids are reasonable. More generally, the VE Bureau and individual units perform the following tasks:
  - VE is involved in scope development, scoping team meetings, independent VE review of developed alternatives, and LCCA.
  - Road User Solutions is involved with road user costs, lane occupancy charges, and incentive/disincentive values that are included in the Special Provisions.
  - Value Solutions is the review unit for the department's Preliminary Design and Final Design submissions with emphasis on roadway, bridge, safety, and traffic operations, and with input from the department's state maintenance engineer as required.

Two agencies focused on specific applications involving the road user-cost component of economic analyses:

- On some projects, road user costs are used for A+B bidding. (A+B bidding is a cost-plus-time bidding process comprising component A, the cost that is bid to perform work, and component B, the time that is proposed to complete work, with the objective of encouraging project completion as soon as possible.) On some projects road user costs have also been used to determine the level of early completion incentives on some projects and are involved in comparing construction plans. (On this topic, refer also to the Accelerated Project Delivery case example in chapter three).

TABLE 3
USE OF ENGINEERING ECONOMIC ANALYSIS AT DIFFERENT STAGES OF DECISION MAKING

Investment Program	Planning	Programming	Resource Allocation	Project Design and Development	Bid Evaluation (e.g., for Best-Value Procurement)	Other Stage of Decision Making	No. of States Reporting EEA Use
Pavements	9	9	7	18	6	1	20
Bridges, Other Structures	10	11	8	14	4	1	18
Other Asset Preservation	6	4	3	6	2	1	9
Urban Congestion Relief: Capacity Expansion	9	5	3	9	1	1	13
Urban Congestion Relief: ITS Strategies	8	4	3	9		1	13
Urban Congestion Relief: Other Operations Improvements	6	3	2	7		2	10
Rural Mobility	6	2	2	5		1	8
Safety	10	9	6	12			15
Economic Impact	5	3	2	1		1	8
Environmental Impact Mitigation	6	1	3	8	1		9
Other	1		1	2	1		—
Totals	76	51	40	91	15	9	—

Source: Synthesis screening survey.
Notes: No. of States = Number of DOTs or FHWA division offices reporting, excluding duplicates within a state; EEA = engineering economic analysis; — = Total not meaningful.

TABLE 4
USE OF ENGINEERING ECONOMIC ANALYSIS AT DIFFERENT TRANSPORTATION SYSTEM LEVELS

Investment Program	Project Level	Corridor Level	Program Level	Network Level	Cross-Program Tradeoffs	Other System or Program Level	No. of States Reporting EEA Use
Pavements	20	6	14	11	4	0	20
Bridges, Other Structures	18	5	10	7	5	0	18
Other Asset Preservation	8	3	3	4	2	1	9
Urban Congestion Relief: Capacity Expansion	11	6	6	4	3	0	13
Urban Congestion Relief: ITS Strategies	8	4	8	2	2	1	13
Urban Congestion Relief: Other Operations Improvements	8	2	4	2	1	2	10
Rural Mobility	6	4	3	3	1	2	8
Safety	15	9	11	6	3	0	15
Economic Impact	4	4	2	1	0	2	8
Environmental Impact Mitigation	9	4	2	2	0	0	9
Other	2	1	1	0	0	0	—
Totals	109	48	64	42	21	8	—

Source: Synthesis screening survey.
Notes: No. of States = Number of DOTs or FHWA division offices reporting, excluding duplicates within a state; EEA = engineering economic analysis; — = Total not meaningful. For purposes of this table: Program Level includes all projects collectively within a single investment program. Network Level projects address particular investments (typically in urban congestion relief or rural mobility) that result in spatial or temporal shifts in demand from one link or time period to another.

- The planning unit within another agency uses BCA when alternate routes are being evaluated for selection based on differences in their respective road user costs.

Integration Within Business Process

New Jersey DOT On an annual basis, the New Jersey DOT prepares asset management plans, which are instrumental in developing the department's Statewide Capital Investment Strategy (SCIS). The SCIS is a performance-based decision-making process that evaluates alternative investment scenarios and produces desired and constrained investment targets for each asset category. SCIS is used to guide the resource allocation strategy for the development of the 10-Year Capital Plan.

A strategic resource allocation process has been conducted that applies performance measures to guide the determination of program category investment targets required to achieve agency goals and objectives over the next ten years. It involves classifying all of the capital work done into program categories and establishing goals, objectives, and performance measures for each category.

Quantitative performance analyses have been conducted, when possible, for highway and mass transit assets. Qualitative performance analyses were used when sound data were not available or could not be technically applied to gauge the performance of a particular category. For example, data for state highway infrastructure are inventoried and life-cycle cost performance curves developed and analyzed using various management systems data for bridge and roadway assets including pavement and drainage condition information. Performance data are also applied from the congestion and safety management systems to conduct prioritization evaluations for alternative budget scenario evaluations. The process to select the Recommended Constrained Investment Targets makes every effort to optimize the overall performance of the budget. This approach tries to make certain that scarce financial resources are used as economically as possible to address their most important needs. Several investment target options are designed to achieve various performance levels for each program.

Washington State DOT Washington State DOT (WSDOT) uses economic analyses in the system planning, scoping, prioritization, and investment tradeoff phases. (Refer to several WSDOT case examples in chapter three.)

Executive Use of Economic Information

Agencies were asked to respond "Yes" or "No" as to whether economic analysis results were reviewed by executive management. Fifteen of the 20 agencies using economic analyses reported executive-level use of this information. Among those that responded "Yes," several provided additional comments:

- Economic data and results for pavement selection are evaluated by a team of senior managers within the SHA when the life-cycle costs analysis results between different alternatives are within 20% over a 40-year period. Other noneconomic factors are included in this discussion when the economic factors and consensus are reached for pavement type selection. With regard to the pavement system preservation program, the chief engineer and administrator review the program's performance targets and budget allocation plan after they are developed and before approval and delivery (Maryland SHA).
- Summary results of network/program-level economic analysis for pavements are presented to upper management (Maine DOT).
- When cost analyses are used in a project analysis, the bureau administrators present the results to the Commissioner's Office to support their proposed alternative. Program analysis in pavements is nearly ready to implement (New Hampshire DOT).
- Information related to bridges is used for the Pennsylvania DOT's Accelerated Bridge Program (Pennsylvania DOT).
- Pavement life-cycle analysis results are used by management to facilitate decisions on pavement type (South Carolina DOT).
- Executive-level managers review pavement, bridge, and safety (Utah DOT).
- Reporting results also includes presenting some of this information to the public through performance reporting in WSDOT's *Gray Notebook.* Recently, WSDOT began presenting a portion of this information to the governor as part of [statewide] performance reporting (WSDOT).

Shared Vision Among Agencies

California's response noted that economic analysis plays a role in helping create a shared vision of transportation among agencies at different levels of government. It is intended that transportation agencies at various governmental levels throughout the state will use engineering and economic analysis from planning through operations, preservation, and maintenance:

> Through the use of management systems, engineering and economic analysis, and other tools, MPOs/RTPAs [Regional Transportation Planning Authorities] and transit operators can more comprehensively view the big picture and evaluate collected data before making decisions as to how specific resources should be deployed. Asset management principles and techniques should be applied throughout the planning process, from initial goal setting and long-range planning to development of the TIP [Transportation Improvement Program] and then through operations, preservation, and maintenance. . . . *Source:* California's 2010 Regional Transportation Planning Guidelines, as cited in California's screening survey response.

On a related note, the literature review and case example development conducted for this synthesis indicated that other state DOTs play an important role in assisting their local agencies with methods and tools to conduct EEAs.

Other Responses

Because this was a screening survey to help identify candidates for further study in chapter three, the results are not intended as statistically representative portrayals of nationwide positions on EEA. In particular, only three states claimed that they do not use EEA in highway investment decision making, whether reported by the state DOT itself or by the FHWA division office. All three provided rationales for this position, which are summarized here. Because of the small sample and that not all responses came directly from the state DOT, these comments are summarized for completeness in reporting the survey and as examples of selected state DOT opinion. They are not necessarily indicative of nationwide practice or thought.

The states that claimed that they do not use EEA on a routine, consistent basis cited one or more of the following reasons:

- Matters of relative priority, lack of a champion, and lack of an effective plan for implementation hinder advances in this area.
- Use of economic analyses is limited to occasional, selective applications, with limiting factors including:
  - political forces driving decisions;
  - questionable assumptions in modeling, leading to variability of results depending on particular assumptions and inputs;
  - lack of available data;
  - lack of confidence in certain data (with engineering judgment preferred);
  - infrequent uses of engineering economic methods that focus on special types of projects (e.g., design–build);
  - while planning to consider the use of economic methods in the future, acknowledging the difficulty of selling the plan now in times of tight budgets (because the need now is to consider initial project costs and to distribute project funding throughout the state, diminishing the importance of the long-term view);
  - the complexity and time involved in developing an EEA;
  - the perceived tendency of a BCA to favor a single type of safety treatment rather than a more diverse program of multiple types of treatments; and
  - litigation concerns with safety programs evaluated through BCA.

PREVIEW OF CASE EXAMPLES

The information in this chapter has provided the foundation for the case examples in chapter three, introducing the methods of EEA typically used to inform decisions on transportation investments, drawing on U.S. and international experience. It has outlined the broad guidelines issued by the federal government and professional associations at the national level for performing highway-related economic analyses in the United States. It has discussed issues in applying economic analyses, including methods to mitigate the risk and uncertainty that are inherent in these types of assessments; identified shortcomings in the analytic methods and data required; and noted other problems that impede wider use of economic methods. It has established, through a screening survey of state DOTs and FHWA division offices, general characteristics of existing practice that have contributed to the selection of the set of case examples and that provide a context for the cases.

The case examples build on this information base. Each case provides more detailed information on governing policies, amplifying the federal requirements discussed in this chapter and adding state-level and agency-specific guidance. After developing the context and rationale of a case, the chapter three descriptions explain the particular economic analyses used, the measures of technical and economic performance appropriate to the case, and how these results are incorporated within highway investment decision making, including non-economic and non-quantifiable considerations where appropriate. The cases have been selected to illustrate a broad range of examples in terms of highway programs (e.g., mobility, safety, preservation, and program-level tradeoffs); the stage of decision making (e.g., planning, programming and budgeting, and resource allocation); and the level of the highway system to which the analysis applies (e.g., project, corridor, program, and network).

The screening survey results showed that most state DOTs use economic analyses for at least certain types of projects; for example, pavement and bridge preservation, safety improvement, major projects, and urban mobility. What differentiates the exemplary case examples in chapter three from this broader participation in EEA? One item, mentioned in the previous paragraph, is the wider scope of application across programs, decision-making stages, and levels of the highway system analyzed. The characteristics go deeper, however, into several aspects of an agency's makeup and its approach to solving transportation problems and needs; for example, the influence of organizational champions and culture; a level of knowledge and comfort regarding use of economic methods; a tighter integration of business and decision processes that make economic analyses a part of routine business rather than a distinct, somewhat isolated task; the willingness to be creative in defining alternative solutions, and to innovate in devising the methods and measures of analysis; that upper management asks for and uses the results of economic analyses in its decision making; the availability of information technology to support not only the economic analyses but also important steps such as diagnosing problems, defining realistic alternatives, and displaying results; the training of staff and provision of resources such as formal guidelines and websites on economic concepts and methods; and, perhaps most importantly, the recognition that economic outcomes are an integral part of gauging highway system performance.

For purposes of this synthesis, this latter subset of agencies will be referred to as those "conversant" with engineering economic methods. This label will distinguish them from other agencies that may apply economic methods, but in a less intensive way to a more limited scope of decisions. The case examples in chapter three will demonstrate characteristics of selected conversant agencies; chapter four will revisit

TABLE 5
POTENTIAL APPLICATIONS OF ENGINEERING ECONOMIC ANALYSIS THROUGH THE PROGRAM DECISION CYCLE

Decision-Making Stage	Example EEA Applications	Selected Illustrations in Case Examples in Chapter Three
Set Policy Goals, Objectives, and Performance Measures	• Translate aspirational goals into practical, achievable objectives • Define performance measures that can be incorporated within EEA analyses • Set performance targets using engineering and economic criteria	Although EEA is not described at this stage in case examples, the cases illustrate explicitly or implicitly how goals, objectives, and performance measures drive decision making. This guidance is established in a practical, meaningful way for use in subsequent decision and evaluation stages.
Planning	• Assess realistic, economically viable alternatives for future major projects • Assess alternatives in corridor-level or network-level transportation improvements • Assess options for systematic improvements at a program level	• Refer to the Critical Facilities case example • Refer to the Critical Facilities case example • Refer to the Mobility Planning case example
Programming and Budgeting	Apply EEA potentially at several steps: 1. Assess project options, select best 2. Rank or prioritize projects in programs 3. Develop realistic candidate programs 4. Conduct program tradeoffs Recommend program budgets based on results of previous analyses	Refer to the following case examples: • Mobility Programming, • Safety Programming, • Bridge Programming and Permitting, and • Economics-Based Tradeoff Analysis
Resource Allocation Following Legislative Budget Approval	• Update proposed programs and projects based upon legislative budget approval, for use in resource allocation • Realign economics-based program or project objectives and performance targets if needed	• Refer to the Economics-Based Tradeoff Analysis case example —
Decisions on Program Delivery: Project Design and Development	• Assess design options from an economic standpoint • Assess capital–maintenance tradeoffs, including user costs as a gauge of road performance	• Refer to the Pavement Type Selection and Value Engineering case examples —
Decisions on Program Delivery: Options in Project Construction	• Assess the most economical strategy for project construction (including a design-build option) • Assess potential applications of new construction approaches (e.g., performance warranties), and use of innovative materials and technology	• Refer to Accelerated Project Delivery case example —
Bid Evaluation; e.g., for Best-Value Procurement	• Incorporation of economic analysis as part of a best-value bid evaluation algorithm	—
System Monitoring, Performance Assessment, and Feedback to Policy Stage	• Validation of project and program decisions in terms of outcomes: engineering performance and economic results • Adjustment of assumptions and parameters used in economic analyses	• Refer to follow-up studies described in the Safety Programming case example —

Notes: — = No case in chapter three corresponds to the example application in the second column. EEA = engineering economic analysis. Decision stages in the first column are illustrative. Actual practices within individual agencies may vary in their order and content, but the intended business processes should be clear.

the themes that differentiate these agencies from the larger population of transportation organizations, to identify more fully the factors underlying successful applications of EEAs.

A brief overview of the cases is provided in Table 5, indicating for each stage of decision making the types of uses to which EEAs may be applied and the corresponding case example in chapter three. Additional information on the methods used in each case and the level of the highway system at which they are applied is given in Table 6. All told, there are 12 case examples of engineering economics applications, including a "case within a case" in the Critical Interstate Facilities example. Furthermore, chapter four draws on lessons gained from the set of case examples plus additional state DOT interviews and literature searches to present several aspects of successful implementation of engineering economic methods—in effect, an extension of the 12 cases to a "thirteenth case" drawn from current industry practice.

TABLE 6
CHARACTERISTICS OF CASE EXAMPLES

Decision-Making Stage	Relevant Chapter Three Case Examples	System Level at Which Analyzed	Methods Illustrated
Set Policy Goals, Objectives, and Performance Measures	Although engineering economic analysis is not described at this stage in case examples, the cases illustrate explicitly or implicitly how goals, objectives, and performance measures drive decision making. This guidance is established in a practical, meaningful way for use in subsequent decision and evaluation stages.		
Planning	Critical Interstate Facilities	Corridors and Networks: • Regional highways • International maritime shipping	• Road user costs avoided • Benefit–cost + risk analysis (scenarios)
	Mobility Planning	Program	B/C analysis, NPV; adjust for uncertainty
Programming and Budgeting	Mobility Programming	Program	B/C analysis, NPV
	Safety Programming	Program	Benefit–cost
	Bridge Programming and Permitting	Project	Cost-effectiveness + utility
	Economics-Based Tradeoffs	Corridor, Network	Excess road user costs
Resource Allocation Following Legislative Budget Approval	Economics-Based Tradeoffs	Corridor, Network	Excess road user costs
Decisions on Program Delivery: Project Design and Development	Pavement Type Selection	Project (two DOTs described)	NPV + risk analysis (probabilistic)
	Value Engineering	Project (two DOTs described)	B/C analysis, NPV
Decisions on Program Delivery: Options in Project Construction	Accelerated Project Delivery	Project	Comparison of discounted costs and discounted benefits + risk analysis* (probabilistic)
Bid Evaluation; e.g., for Best-Value Procurement	—		
System Monitoring, Performance Assessment, and Feedback to Policy Stage	Safety Program: Follow-Up Analyses	Program: Assess performance and economic results to validate future program guidance	Cost-effectiveness

Decision stages in the first column are illustrative. Actual practices within individual agencies may vary from these in order and content, but the intended business processes should be clear. For explanation of System Levels in column 3, refer to description of Scope of Work in chapter one. For explanation of Methods Illustrated in column 4, refer to discussion of Engineering Economic Methods in chapter two. B/C = benefit-cost; NPV = net present value.
*The objective of this study was to explore the development of a methodology for future application to project delivery options, and not to inform an actual decision.
Notes: — = There is no case example at this decision-making stage.

CHAPTER THREE

CASE EXAMPLES

IMPACT OF CRITICAL INTERSTATE TRANSPORTATION FACILITIES

Introduction

The Port Authority of New York and New Jersey (PANYNJ) is a regional public authority established by bi-state charter that operates a number of multimodal transportation facilities within its defined Port District. It has responsibility for major interstate transportation facilities, including six highway crossings between New York and New Jersey and transportation stations and centers in both states. It operates three major metropolitan airports and two regional airports, several marine facilities, and transit lines with ferry connections to Manhattan. The PANYNJ also oversees reconstruction of the World Trade Center in Lower Manhattan ("The Port Authority . . ." n.d.; "Overview of Facilities and Services" 2010). Despite the significance of its existing transportation infrastructure and resulting impacts to the movement of people and goods throughout the metropolitan region, PANYNJ before 2000 had not attempted to quantify comprehensively the economic benefits conferred by its transportation infrastructure. This case describes the first step in that quantification: the estimation of the economic benefits of PANYNJ's interstate transportation facilities. Although the Port Authority's own study considered several categories of infrastructure outlined previously, this case example focuses specifically on the six bridges and tunnels between New York and New Jersey; facilities that can be regarded as critical infrastructure in terms of the impact of highway investment on local and regional economic conditions. The data and methodology used in this effort form part of a proposed regional cost–benefit capability described here. The case is unique given the network-level significance and criticality of the transportation facilities involved. Within the framework of this synthesis, it provides an example of planning information developed at a corridor and network level. The documentary source for this critical facilities case is the economic impact study performed for the Port Authority by a consulting firm (*The Economic Impact . . .* 2000). Other sources relating to a specific issue regarding the Bayonne Bridge will be presented at that point later in the case example.

Role of Economic Analysis in Highway Investment

Facilities

The Port Authority's transportation facilities are located in the New York–New Jersey metropolitan region as illustrated in Figure 1. The Port Authority Interstate Transportation Facilities (PAITF), which is the focus of this case example, is a subset of the facilities in Figure 1 comprising the following:

- Highway Bridges and Tunnels
  - George Washington Bridge, Goethals Bridge, Outerbridge Crossing, Bayonne Bridge
  - Lincoln Tunnel, Holland Tunnel.
- Interstate Transit Links
  - Port Authority Trans-Hudson (known as PATH) transit service
  - Coordination of transit service with ferry services to downtown and midtown Manhattan that are provided by other operators.
- Transportation Stations and Centers
  - Port Authority Bus Terminal
  - George Washington Bridge Bus Station
  - Journal Square Transportation Center.

Daily use of these facilities is shown in Table 7, which organizes the facilities into four major corridors. This traffic represents the major share of commuter and freight flows between New York and New Jersey. The PAITF are critical links within the highway, transit, and rail networks that serve the New York–New Jersey metropolitan region shown in Figure 1. These networks connect New York City, Long Island, the northern suburbs of New York, other points north, other points east of the Hudson River, the northern suburbs of New Jersey, and other points west of the Hudson River. The Midtown Corridor shows substantial road traffic in the Lincoln Tunnel. This tunnel, which provides an exclusive bus lane, is a major transit corridor into midtown Manhattan. The Port Authority's report includes a separate estimate of the benefits of this bus traffic. In addition to the PAITF, rail and transit services to midtown are provided by Amtrak, New Jersey Transit, the Metro–North Railroad, the Long Island Rail Road, New York City Transit, and private commuter bus and ferry services.

Components of the Analysis

Three components of economic benefit were considered in the Port Authority study of the PAITF:

1. *Transportation benefits,* comprising savings in travel time and VOC resulting from the existence of a PAITF facility.

FIGURE 1 Locations of PANYNJ transportation facilities. *Source:* Port Authority of New York and New Jersey, http://www.panynj.gov/about/facilities-services.html.

TABLE 7
DAILY USE OF PAITF, 1999

Corridor/Facility	Weekday Use	Weekend Use	Measure of Use
Northern Corridor			
George Washington Bridge	151,700	149,000	Vehicles
Midtown Corridor			
Lincoln Tunnel	62,200	57,400	Vehicles
PATH Service to 33rd Street	41,300	21,600	Passenger trips
Midtown Ferry Service	11,500	6,100	Passenger trips
Downtown Corridor			
Holland Tunnel	49,700	49,500	Vehicles
PATH to World Trade Center	60,400	13,400	Passenger trips
Downtown Ferry Service	12,500	1,500	Passenger trips
Southern Corridor			
Goethals Bridge	36,000	38,000	Vehicles
Outerbridge Crossing	40,900	45,900	Vehicles
Bayonne Bridge	9,700	7,000	Vehicles

Source: *The Economic Impact…* (2000).

2. *Operating and capital impacts,* the result of expenditures on the Interstate Facilities by the Port Authority, its tenants, and other transportation providers. These expenditures purchase goods and services from regional businesses that support the maintenance, operation, and enhancement of the facilities. The result is not only an improved level of transportation service, but also an improved economic welfare of the region resulting from direct purchases and subsequent indirect purchases owing to PAITF expenditures.
3. *Competitive impacts,* which result from more efficient access to, and movement within, the region served by PAITF. This benefit reflects the improved economic competitiveness and stimulation of growth owing to services provided by the Interstate Facilities in several categories; for example, commuter trips between New Jersey and New York, tourist travel, intra-regional and longer-distance trucking shipments, and direct economic development occurring around and surrounding PAITF locations.

This synthesis focuses on the first of these benefits categories, direct transportation benefits, and on the bridges and tunnels specifically, because these tend to be the most prevalent for consideration in LCCAs for highway investment.

Methods and Measures

Analytic Principle

A methodology was needed to address the quantification of benefits resulting from facilities of different modes, characteristics, and usages, located within an extensive metropolitan, multimodal transportation network. The principle that was adopted was that the benefits of an existing facility would be equal to the additional costs to all travelers if that facility were removed from the network. Worded more formally in the Port Authority report:

> The transportation benefits of a facility are defined in this [Port Authority] study as the value of increased travel costs, consisting of travel time and vehicle operating costs, that displaced users would incur if that facility were no longer available, and all other network facilities remained open. *Source: The Economic Impact* . . . 2000, p. 5.

The Port Authority believed that this estimate was conservative in the following sense: If two or more Interstate Facilities were closed down simultaneously, the overall cost impacts would likely exceed the sum of the costs of individually removing each of these facilities from the network. The Port Authority also realized that highway-user costs would differ among facilities for several reasons, including wide variations in origin–destination points among respective road users, the convenience of the preferred river crossings perceived by users, the convenience and travel cost of available alternate routes, and existing levels of congestion. The Port Authority's study offered the following examples to illustrate these points.

> . . . closing the George Washington Bridge imposes a high increase in travel time on its users principally because alternative river crossings (primarily the Holland and Lincoln Tunnels) are relatively distant and the sheer volume of present users at the George Washington Bridge would cause grave congestion problems at these alternative crossings. On the other hand, closing the Holland Tunnel would lead to significantly smaller increases in travel costs because the existing traffic at the Holland Tunnel is much lower . . . and alternative facilities are both relatively near and capable of absorbing the increase in traffic. Similarly, while the Goethals Bridge and Outerbridge Crossing serve overlapping markets and have similar traffic levels, the analysis magnifies the impact of the latter bridge because it does not have as many nearby alternatives as the former. *Source: The Economic Impact* . . . 2000, p. 5.

Methodology

With this guiding principle established, the calculation of benefits was organized within a methodology that entailed four basic assumptions governing the determination of needed input values. These assumptions involved value of road users' time, value of VOC, the degree of diversion to transit, and projection of traffic volumes to year 2000, the base year of the analysis.

- **Value of road users' time.** Value of time was estimated based on relationship to wage rates and variations based on trip purpose. The assumed values of time were as follows: working time during transportation (e.g., truck and bus drivers) is equal to the gross wage; commuting time is equal to 50% of the gross wage; and leisure time (or personal travel) is equal to 25% of the gross wage. Values of the gross wage were estimated based on the average wage in the vehicles' *destination* county in the a.m. travel period (from origin–destination data), because the destination would be an indication of work location for commuters. Destination county was also used to estimate the wages of those in heavy-goods vehicles, factored at 100% of the county's average wage. The value of travel time associated with each vehicle also accounted for average vehicle occupancy.
- **Value of VOC.** VOC include the costs of fuel, oil, tire wear, and vehicle maintenance, plus an allowance for the capital cost of the vehicle. A literature review was conducted to estimate the following composite values for the New York metropolitan area: $0.29 per mile for autos, $1.20 per mile for trucks, and $0.91 per mile for buses.
- **Diversion to transit.** Some of the road users displaced by bridge or tunnel closure were expected to divert to mass transit. An elasticity factor was assumed based on locally available transportation alternatives at each PAITF. This elasticity of transit use to auto travel time was estimated to be 0.15 to 0.3, with the study assumptions leaning toward the higher end of this range. For example, an elasticity of 0.25 would mean that for every 10% increase in auto travel time, transit use

would increase by 2.5%. This range of 0.15 to 0.3 was somewhat lower than values appearing in the literature at the time of the study (extending to 0.8). The lower values were believed to be more realistic for this particular study; however, because other studies had found relatively inelastic behavior of auto travelers on trans-Hudson crossings with respect to diversion to transit.

- **Projected traffic volume.** Available traffic data were projected to the study year (2000) to arrive at 24-hour weekday distributions, which served as a basis for assuming traffic volume inputs.

Other data were applied to complete the estimate. For example, survey results were available to enable estimates of average vehicle occupancy on certain of these bridges and tunnels, as well as trip purpose.

The Interstate Network Analysis (INA) model was used to simulate the closing of individual bridges and tunnels and the resulting "shock" impacts throughout the network. These impacts consisted of rerouting the displaced vehicles to the "best" available alternative based on their origin–destination data, and then rerunning the INA model to compute a new network equilibrium. The model did not assume any peak shifting as the result of these diversions, regardless of the level of congestion and increased travel time to the road users. Moreover, the focus of the calculations was on the change in travel costs to the former users of the closed facility, not to the users of other facilities in the network. (This assumption is another indication that the estimate of transportation benefit conferred by each Interstate Facility was conservative.) The INA model then reported the net increases in travel time and distance for road users, which were converted to costs using the travel time and VOC inputs discussed earlier.

The results of this analysis show that the George Washington Bridge has greater benefits than the other crossings, for the reasons cited earlier: heavy travel demand and the lack of alternate crossings nearby. Results for each bridge and tunnel are also available disaggregated into three line items that respond to the imposed closure of a facility: the cost of increased travel time experienced by former users of the facility who must now divert to alternate routes; the increased time for former facility users who are now diverting to transit; and the increased cost of vehicle operation by former users of the closed facility.

Decision Support

Background Information

The economic analysis described earlier provides a point of departure for more comprehensive and detailed analyses of the roles that these critical interstate transportation facilities serve at a regional and national level. As an example, the following paragraphs frame a transportation issue that PANYNJ is now dealing with that involves significant investment needs as well as significant impacts to regional highway transportation and, potentially, to national and international maritime shipping. The issue is multimodal and multijurisdictional: it involves benefit–cost applications in both a regional and a national context.

The issue concerns the Bayonne Bridge, which is shown at the lower-left-hand area of Figure 1. The bridge carries a highway link between Bayonne, New Jersey and Staten Island, New York. The body of water that it crosses, the Kill Van Kull, is the entrance westward to the Port Authority's maritime facilities, also shown in Figure 1. The current height of the bridge over the water (151 ft), referred to as its air draft, is becoming a limiting factor on shipping entering the port because of the increasing size of cargo ships worldwide. This growth in the dimensions of large container ships is expected to increase when the capacity expansion of the Panama Canal is completed by 2015. The Port Authority recognizes a dual set of objectives and needs regarding issues such as this air-draft constraint: to continue providing a world-class port with navigable channels and clearances that can accommodate large cargo vessels and continue to provide the landside infrastructure needed to move cargo ("Next Steps to Address . . ." n.d.).

USACE Air Draft Analysis

In 2008, the Port Authority commissioned the New York District of the U.S. Army Corps of Engineers (USACE) to study "the commercial consequences of and the national economic benefits that could be generated by a potential remedy of the Bayonne Bridge's air draft restriction" ("Next Steps to Address . . ." n.d.). The USACE approached the problem by addressing when and to what extent the Bayonne Bridge would present an obstacle to larger ships, what are the economic consequences, and would further planning and environmental analyses of possible solutions be warranted. The report was conducted in the nature of a Corps reconnaissance study, rather than a feasibility study, in that it did not recommend a specific project or cost-sharing plan. However, it did provide technical and economic data responsive to the Port Authority's planning and decision-making needs. The primary findings of this study included the following (*Bayonne Bridge Air Draft Analysis* Sep. 2009):

- The current height of the Bayonne Bridge is and will be an obstruction to larger container vessels within a 50-year analysis horizon.
- Based on preliminary estimates addressing a range of engineering solutions to the air-draft problem, all have favorable benefit–cost ratios as summarized in Table 8.
- Further planning and environmental analyses by the Port Authority are warranted to identify a preferred solution to the air-draft restriction.

The current Bayonne Bridge structure is a steel arch with cables suspended from the arch to support the roadbed. The

TABLE 8
SUMMARY OF BENEFIT–COST RESULTS, USACE AIR-DRAFT STUDY

Alternative	Year the Improvement Is in Place	Break-Even Year	Benefit–Cost Ratio	Internal Rate of Return	Net Benefit, $Billions
Jack Structure to 215 ft	2019	2033	3.0	10.7%	$3.271
New Structure at 215 ft	2022	2039	2.1	8.4%	$2.822
Bored Tunnel	2024	2042	1.9	7.7%	$2.585
Immersed Tunnel	2024	2051	1.4	6.1%	$1.517

Source: *Bayonne Bridge Air Draft*… Sep. 2009, Tables 4 and 6.

USACE considered the following engineering alternatives to remove the bridge air-draft restriction:

- Jack the existing steel arch and roadbed to a new height providing an air draft of 215 ft.
- Build a new bridge structure with an air draft of 215 ft.
- Bore a tunnel under the Kill Van Kull to replace the existing bridge.
- Construct an immersed tunnel under the Kill Van Kull to replace the existing bridge.

The benefit–cost results for each of these alternatives are shown in Table 8. Costs were estimated using data provided by PANYNJ's Tunnels, Bridges & Terminals Department, based on the start of detailed engineering and design in 2010. Facility operation and maintenance (O&M) costs were estimated for each alternative, using the 50-year analysis period with O&M costs commencing at the completion of construction. Benefits were estimated according to National Economic Development (NED) guidance, discussed here. Benefits were assumed to commence at the completion of construction of each alternative as shown in Table 8, including removal of the constraining roadbed from the channel. Net present value, benefit–cost ratio, and IRR of the cost and benefit streams were computed using a discount rate of 4.625% over a 50-year analysis period. The USACE also projected 50-year forecasts on the characteristics of shipping to the Port of New York and New Jersey (PONYNJ) in the absence of alteration or replacement of the Bayonne Bridge (i.e., the No-Build option) (*Bayonne Bridge Air Draft Analysis* Sep. 2009, pp. 32–36, Appendix B).

Federal objectives and guidelines regarding studies of water and related land/resources development are spelled out in a document prepared by the U.S. Water Resources Council (*Economic and Environmental Principles* . . . Mar. 1983). The federal objective in project planning involving these resources is "to contribute to national economic development consistent with protecting the Nation's environment," and to do so in compliance with relevant federal statutes, executive orders, and other planning requirements (*Economic and Environmental Principles* . . . Mar. 1983, p. iv). Project plans might address problems and explore opportunities to meet this objective, including identification of project benefits that contribute to NED. Contributions to NED are defined as "increases in the net value of the national output of goods and services, expressed in monetary units" (p. iv). Contributions to NED may occur within the study region, or elsewhere in the nation as the result of the project. That NED reflects a net increase in total output implies real gains attributable to the project on a nationwide basis, not simply a transfer of benefits from one region of the country to another.

Benefits of the proposed Bayonne Bridge project were analyzed in terms of the reduced costs of maritime shipping owing to economies of scale in using larger vessels. To compute this cost reduction, USACE formulated two future possibilities: (1) the Without-Project (or No-Build) condition, in which maritime commerce entering PONYNJ would be carried in smaller, less economically efficient vessels that could operate with the restricted air draft of the Bayonne Bridge; and (2) the With-Project condition, in which the existing air-draft constraint is removed by bridge alteration or replacement, allowing larger, taller vessels to be added to New York-bound routes. The USACE analysis forecast the amount of freight commerce through PONYNJ over a 50-year analysis period. It also forecast changes in the worldwide shipping fleet with the addition of the larger container vessels, contrasting the fleets to be used in Conditions 1 and 2. The USACE analysis then in effect "loaded" the two fleets with the projected cargo volumes, estimated the number of trips and container-miles required for the With-Project and Without-Project assumptions, and computed the respective vessel operating costs in each case. The difference between these two shipping-cost totals was taken as the NED benefit attributable to the project (*Bayonne Bridge Air Draft Analysis* Sep. 2009, pp. 12, 13, 32, 33).

USACE dealt with a number of issues in formulating this economic benefits study (*Bayonne Bridge Air Draft Analysis* Sep. 2009, pp. 13–32):

- The trends in several inputs to the benefits computation had to be estimated through the 50-year analysis period.

These trends included a forecast of commerce through PONYNJ, the characteristics of the future maritime fleet, likely patterns of fleet use on routes bound for U.S. East Coast ports, loading patterns in accommodating cargo on different types of vessels while conforming to the operational needs of regularly scheduled service worldwide (i.e., ships depart ports on a schedule, whether or not fully loaded), how the vessel fleets should be deployed in the analysis to handle growth in cargo volume for the With-Project and Without-Project conditions respectively, and estimation of the costs of operating vessels in the With-Project and Without-Project fleets.

- USACE also had to address other potential restrictions on shipping that might negate the benefits of the Bayonne Bridge project. For example, if PONYNJ harbor channels were not deep enough to handle large vessels, the prospective benefits of increasing the air draft on the Bayonne Bridge might never be realized. On this particular point, an earlier Harbor Navigation Study (HNS) had been performed in 1999, recommending deepening of several channels in PONYNJ; construction funding for this project was authorized by the U.S. Congress in 2000. For a number of positive reasons, USACE applied the NED methodology used in the Harbor Navigation Study to its air-draft study. This consistency of method made it possible for the Corps to ensure that the benefits of the air-draft project were separate and distinct from the benefits of the harbor deepening work, avoiding double-counting or overstating of benefits.
- Other external factors and constraints could also limit the actual benefits to be realized from the Bayonne Bridge project, along the lines suggested in the preceding item. For example, possible limitations in rail and highway capacity, port crane capacity, berthing space, and yard capacity could themselves limit the volume of cargo handled by PONYNJ, apart from restrictions imposed by the bridge air draft. Also note that the Bayonne Bridge is not an obstacle to port facilities located eastward, so greater use of these port facilities could increase benefits regardless of whether or not the air-draft constraint were removed. (This is not to say that such capacity constraints actually existed. USACE was just pointing out that a valid evaluation of benefits needed to consider these other factors, which was done in a broad context in developing the findings of the air-draft study.)
- A similar point related to more global constraints—the USACE further considered whether these might limit the benefits that could be realized by altering or replacing the Bayonne Bridge. A key global constraint was the existence of air-draft restrictions in other parts of the world, which might themselves constrain the heights of future maritime fleet additions. The Corps investigated these and found that although certain height limits did exist, the air draft of the Bayonne Bridge was the most constraining among those affecting 12 major ports worldwide.

USACE further considered other factors that might influence future decisions on the project, and conducted scenario analyses to investigate the effects of differing assumptions underlying the study.

- The Corps recognized factors that were outside the scope of its study, but that could inform and affect PANYNJ's decisions on how to proceed on this project. These included regional and local economic benefits and impacts (as compared with the national benefits computed in the air-draft study); the possibility that not all NED benefits were accounted for in the study (maritime transportation cost savings tend to be used as a NED benefit measure because they are relatively conservative and easier to compute than other categories of benefits); and that although the study referred generally to "the Port of New York and New Jersey," the Port comprises a number of stakeholders to whom benefits will accrue; for example, ocean carriers, terminal operators, labor interests, land-side transportation providers, and regional consumers (*Bayonne Bridge Air Draft Analysis* Sep. 2009, pp. 37–38).
- The Corps recognized several areas of potential uncertainty in the analysis, and subjected each to scenario testing in which key parameters or assumptions were varied to assess their impact on the economic results. Nine categories of scenario analyses were addressed in all, covering diverse aspects such as the projections of maritime commerce, shifts in the location of manufacturing in Asia and their effect on shipping to the East Coast, project cost estimates, different engineering options in the height to which the bridge roadway might be raised, and delays in the start of design and construction, among others. For a given category, the scenarios comprised several repetitions of the analysis, each repetition testing a different parameter value or assumption. Results of each repetition provided information comparable to that shown in Table 8.

Coming PANYNJ Analyses

The USACE analysis demonstrated that the Bayonne Bridge project was justified economically from a national perspective. This result opened the door for the Port Authority to conduct its own technical and economic analyses of the project and how it might proceed. As the contact representative of the PANYNJ has pointed out, the roles of the respective economic analyses can be understood essentially as follows: the USACE analysis indicated that the project is justified at a national level, whereas the PANYNJ analysis will indicate whether the regional benefits exceed the costs. The coming PANYNJ regional analysis will examine issues not addressed in detail in the national study; for example, a more comprehensive assessment of highway-user benefits addressing the land-side facilities of PONYNJ (including traffic over the Bayonne Bridge during and after construction), and changes in maritime air pollution emissions because of the anticipated shift in vessel fleet characteristics calling on PONYNJ as the result of the modified air draft.

In December 2010, the Port Authority announced that its preferred engineering option for the Bayonne Bridge would be a reconstruction of the main-span roadbed and bridge approaches and ramps, to raise the roadbed as it crosses the channel through its supporting steel arch. As of March 2011, PANYNJ was proceeding to identify and select an engineering consultant to provide design services for this project.

Resources Needed and Other Information

Resources

The PANYNJ's study of the economic impacts of its transportation infrastructure has been accomplished with the assistance of a consulting firm working with Port Authority staff. Although USACE personnel performed the cost and benefit analysis for the Bayonne Bridge Air Draft study and developed a portion of the input data, it obtained other data from PANYNJ. Corps personnel also met with PANYNJ consultants who were performing comparable analyses on other studies, to compare trend projections and check their consistency.

PLANNING AND PROGRAMMING: MOBILITY AND SAFETY PROJECTS

Introduction

This section presents the methodology now used by WSDOT for highway capital programming, currently being extended to highway system planning. WSDOT's programming process has been in place for almost two decades, and has benefited from continual updating, improvement, and integration within broader statewide performance-accountability initiatives. This case example describes work that is comprehensive, innovative, and unique in the thorough integration of economic thinking from the top-level guidance of enabling state legislation through detailed analysis of the estimated costs, benefits, and technical performance of project alternatives. An extensive information infrastructure has been built to support these procedures in headquarters and region (district) offices. WSDOT's Capital Program Development and Management Office (CPDM) provides overall guidance to this effort in its conception, implementation, and application. Although WSDOT manages programs across several modes and types of work, the processes and economic analyses described here apply only to the highway construction program. It would normally be more natural to explain the planning process first, followed by capital programming. However, given the history of program-development processes at WSDOT, the following description will reflect the chronological order of their implementation: highway capital programming first, followed by the extension to highway system planning.

Role of Economic Analyses in Highway Investment

Background

In 1990, WSDOT began working on a new, performance-based capital programming process under a project sponsored by the (then Joint) Legislative Transportation Committee. It had become apparent by that time that an emerging set of policy issues at the federal and state levels would confront WSDOT and Washington's Transportation Commission, and changes to the highway capital construction programming process would be needed. Key objectives to be met included: (1) a strong, clear connection between the programming process and the emerging policy concerns; (2) a strengthened ability to highlight and evaluate key tradeoffs in funding projects; (3) a more rational, understandable basis for prioritization rooted in economic as well as engineering performance; and (4) incorporation of greater flexibility and accountability in recommending projects. The study was concluded in 1991, and its recommendations were accepted by WSDOT for future implementation. Since that time, the programming process has been continually refined to meet new transportation program needs, accommodate the terms of new legislative requirements and funding sources, update analytic methods and decision criteria, contribute to statewide initiatives in performance-based management and accountability, and incorporate new technology.

Statutory Program Guidance

The Revised Code of Washington (RCW) compiles all permanent laws of the state of Washington; Title 47 deals with public highways and transportation. RCW 47.05, Priority Programming for Highway Development, was rewritten in 1993 as the result of the capital programming study mentioned earlier and enabled WSDOT implementation of the new programming process to be fully implemented. The new statute restructured Washington's highway investment program, introduced new capital construction programming processes that considered least-cost and benefit–cost evaluations of proposed solutions to transportation problems, and responded to new policy initiatives at the state and federal levels. The law has been revised since then to be coordinated with other chapters of Title 47 (e.g., defining legislatively mandated transportation goals) and to fit within an expanding application of performance-based management throughout Washington state government.

The declaration of purpose of RCW 47.05 is as follows, with specific reference to use of economic methods:

> The legislature finds that solutions to state highway deficiencies have become increasingly complex . . . Difficult investment trade-offs will be required.
>
> It is the intent of the legislature that investment of state transportation funds to address deficiencies on the state highway system be based on a policy of priority programming having as its basis the rational selection of projects and services according to factual need and an evaluation of life cycle costs and benefits that are systematically scheduled to carry out defined objectives within available

> revenue. The state must develop analytic tools to use a common methodology to measure benefits and costs for all modes.
>
> The priority programming system must ensure preservation of the existing state highway system, relieve congestion, provide mobility for people and goods, support the state's economy, and promote environmental protection and energy conservation. . . .
>
> The priority programming system for improvements must incorporate a broad range of solutions that are identified in the statewide transportation plan as appropriate to address state highway system deficiencies, including but not limited to highway expansion, efficiency improvements, nonmotorized transportation facilities, high occupancy vehicle facilities, transit facilities and services, rail facilities and services, and transportation demand management programs. *Source:* http://apps.leg.wa.gov/rcw/default.aspx?cite=47.05.010.

Legislatively mandated goals for the transportation program are as follows (RCW 47.04.280):

- **Economic vitality:** To promote and develop transportation systems that stimulate, support, and enhance the movement of people and goods to ensure a prosperous economy;
- **Preservation:** To maintain, preserve, and extend the life and utility of prior investments in transportation systems and services;
- **Safety:** To provide for and improve the safety and security of transportation customers and the transportation system;
- **Mobility:** To improve the predictable movement of goods and people throughout Washington state;
- **Environment:** To enhance Washington's quality of life through transportation investments that promote energy conservation, enhance healthy communities, and protect the environment; and
- **Stewardship:** To continuously improve the quality, effectiveness, and efficiency of the transportation system.

Programming Mobility Projects

WSDOT's highway capital construction program is divided into two major components, Preservation (P) and Improvement (I). Specific types of projects are organized within program categories under Programs P and I, respectively. Both major programs employ economic analyses to assist in project ranking and selection, program development, and recommendation of a biennial budget. The Preservation Program generally considers the criterion of lowest life-cycle cost, whereas the Improvement Program is based typically on benefit–cost considerations. Other, nonmonetary factors are also considered in final decisions on P and I projects. The P and I programs are further subdivided into subprograms that contain specific types of projects. This case example addresses one of the Improvement Program subprograms, Mobility.

The Mobility subprogram includes projects addressing urban congestion, rural mobility, urban bicycle connectivity, and high-occupancy vehicle (HOV) lanes. Projects are grouped in this way to enable "peer group" or "apples-to-apples" comparisons among candidates when prioritizing and selecting the best solutions to identified needs or problems. Each program receives an investment target from the legislature; this target anticipates monies from a number of state and federal funding sources, each with separate requirements ("2009–2011 Scoping . . ." Aug. 2007). Recommendation of those high-ranking projects to be constructed within the budget target is the task of the programming process. The process encompasses the following steps (MacDonald Feb. 2004; "WSDOT Projects . . . Prioritization" 2008):

- To identify a problem or need (typically based on findings in the Highway System Plan), based on an identified performance objective or goal.
- To explore possible solutions and advance the most cost-effective and least capital-intensive alternative.
- To develop a project scope that—in addition to estimated effects on transportation system performance—takes into account potential issues in environmental impact, roadway design, and stakeholder reaction, including community acceptance.
- To estimate project costs based on information in the scope and develop a basis of estimate to document all assumptions.
- To estimate project benefits based on information in the scope.
- To compare the benefits and costs of this project with those of its peers to determine project rank and priority.

As part of the Highway System Plan updating process, WSDOT uses multiple tools in screening and evaluating project candidates. CPDM uses the Highway Segment Analysis Program as a screening tool to identify all congested highway segments on the network, complemented by other WSDOT analytic tools (e.g., to identify bottlenecks). Resulting state highway needs are consolidated with road needs identified by MPOs, RTPOs, and tribal nations. Cost-effective solutions are then developed and analyzed using traffic analysis tools to make sure the projects improve performance. Next, the Mobility Project Prioritization Process (MP3) tool is used to analyze the benefits and costs of each Mobility project as affected by its engineering and performance characteristics, to prioritize and rank projects within each subprogram, and to evaluate program tradeoffs in the face of budget constraints.

- **Screening criteria**
  - Candidate projects that are not listed in the Highway System Plan are ineligible for further consideration.
  - To meet air quality conformity requirements, candidate projects that would degrade air quality in nonattainment areas are ineligible for further consideration.
  - Given budget limitations, candidate projects might favor near-term to mid-term needs, rather than solely long-term needs, to warrant further consideration.
- **Evaluation criteria**
  - BCA (discussed in the following section).
  - Environmental impact: wetlands, water quality and permitting, and noise; evaluated on a nonmonetary

basis using either responses to yes–no questions (e.g., regarding permitting requirements) or penalty points and risk-factor points for adverse environmental consequences.
  - Stakeholder response: degree of community support, views of other stakeholders, potential disruption of neighborhoods; evaluated on a nonmonetary basis using responses to yes–no questions.
  - Project design: projected relationship of project to, or expected impact on, matters such as land use, efficient use of existing capacity, network/system connectivity, use of alternative modes including bicycling and walking, and modal integration (both intermodal and packaged multimodal solutions); evaluated on a nonmonetary basis using responses to yes–no questions.

These criteria are weighted, with the benefit–cost criterion having the heaviest weight. The mathematical prioritization considers both economic and nonmonetary criteria. Projects closer to the ideal-best result are higher in ranking; those closer to the theoretically worst result are lower in ranking.

- **Analytic tool**
  - The MP3 analytic tool and its results are described in the following section.
  - To focus the technical discussion of this methodology, the case example considers a particular group of Mobility projects: those that improve highway capacity and operational performance to provide congestion relief.

Mobility Methods and Measures

Engineering Economic Methodology

The BCA of WSDOT Mobility projects is conducted using the Mobility Project Prioritization Process (MPPP or MP3). MP3 is a spreadsheet workbook that evolved from model development by WSDOT through the 1990s, which was improved with additions and modifications by a consultant team in 2000. The MP3 workbook accepts inputs on the type, location, and engineering characteristics of the project; traffic forecasting data; data to estimate benefits in travel-time reductions and collision reductions; and project cost data. MP3 users may also specify changes in key parameters [e.g., discount rate, project life cycle, benefit-days per year, hourly average annual daily traffic (AADT) distribution curves] and the internal representation of speed-flow curves to allow choice between the WSDOT default speed-flow relationship and that in the *Highway Capacity Manual* (*HCM 2000*). In most of the analyses, the benefit of travel-time savings is computed based on the difference in vehicle-hours of travel time with and without the project. For intersection improvements, the benefit of travel-time savings is based on the change in overall delay comparing the build and no-build options (Dowling Associates, Inc. et al. May 2000, p. 9).

EEAs of project benefits are structured individually for each type of Mobility improvement (Dowling Associates, Inc. et al. May 2000, supplemented by review of the current MP3 workbook provided by WSDOT):

- **Mainline lane addition/access management benefits:** addition of general purpose lanes, addition of truck-climbing lanes, addition of a two-way left-turn lane on two-lane highways, and modification of type of median on four- to seven-lane highways.
- **HOV lane benefits:** adding an HOV 2+ lane to an urban multilane highway/freeway, either or both directions; converting a general purpose lane of an urban multilane highway/freeway to an HOV 2+ lane, either or both directions; and conversion of an HOV 2+ lane to an HOV 3+ lane when the HOV-lane volume reaches HOV-lane capacity.
- **Intersection improvement benefits:** originally, improvement of existing signalized intersections based on intersection control; later allowance for improvement of Stop-controlled intersections; later addition of roundabouts as a new type of intersection improvement.
- **New interchange benefits:** new interchange at a new access point.
- **Park-and-ride lot benefits:** road user benefits resulting from constructing a park-and-ride lot adjacent to a state highway; the workbook provides several options on type and location of the parking lot.
- **Safety benefits:** benefits of expected accident reductions owing to the highway improvement; benefits assigned to collision reductions in five categories: fatality, disabling injury, evident injury, possible injury, and property damage only.

Consider the example of the addition of a general purpose lane:

- Input data or internal global values on the proposed lane-addition project, traffic volume and composition, traffic growth rate, and 24-hour distribution of daily traffic are used to estimate the effects on speed and travel time under the build and no-build options, in the analysis base year and the analysis future year. Standard engineering calculations such as those used with the *Highway Capacity Manual* are applied to compute volume–capacity ratios, resulting operating speeds, implied travel times, and travel-time savings resulting from the proposed project.
- Benefits in each of the 24 daily hours are computed using a number of default values within MP3, which can be changed from time to time with appropriate documentation of source and CPDM concurrence. These values include a factor that specifies the number of days per year for which benefits are assumed (i.e., the number of days per year for which the 24-hour distribution of traffic applies; e.g., 260 days per year); wage rates applicable to drivers of general-purpose vehicles and trucks, respectively; together with a multiplicative factor identi-

fying the percentage of wage rate to be used in the benefits calculation (e.g., 50% for general vehicles, 100% for trucks), average vehicle occupancy during peak and off-peak periods, and the travel-time savings computed earlier.
- Benefits are tallied for each of the 24 daily hours and expanded to annual totals for each year of the analysis period using the specified days-per-year figure discussed earlier (e.g., 260 days per year). The value of the discount rate (an MP3 global variable with default value of 4%; deviation from this figure requires WSDOT approval) is used to compute the present value of the benefits stream.
- Project costs are input using data from the project scoping estimate or planning-level cost estimate. Construction cost inputs cover preliminary engineering, right-of-way, and construction of structures, drainage, grading, and other items. Total construction costs are reduced by the amount of cost sharing by agencies other than WSDOT. Operation and maintenance costs are input on an annual basis; a workbook calculation applies these to each year of the analysis period, and computes the present value using the present-value-of-annual-series factor for the specified discount rate and length of analysis period (e.g., 4%, 20 years). The present value of total costs equals the sum of WSDOT construction costs and the present value of operation and maintenance costs.
- The workbook computes the net present value (present value of benefits minus present value of costs) and the benefit–cost ratio (present value of benefits divided by present value of costs).

Results of Analyses

A corresponding approach is used for other types of Mobility projects addressed by the MP3 workbook. A summary of the analytic elements on each workbook tab, including the tabs (or worksheets) for the respective project types, is shown in Table 9. Results for all of these analyses are expressed as net present values and benefit–cost ratios.

Mobility Decision Support

The benefit–cost results for Mobility projects, together with results of corresponding economic analyses for other I and P subprograms, provide the economic input to project prioritization that is critical to WSDOT's development of its capital construction program and biennial budget. The recommended project rankings produced by the analytic programming procedures such as MP3 are helpful in understanding the economic value-to-cost of projects and programs, as well as their relative strengths in other, nonmonetary criteria; however, they do not determine the final budget. Flexibility in the process allows WSDOT to respond to other influences such as community interest and need. Individual projects may be raised in priority and others deferred to compensate within the constrained budget. The legislature may also direct funding to specific projects regardless of their computed priority ("WSDOT Projects . . . Prioritization" 2008).

These results of the programming process are reviewed internally by department executives and other senior managers. Externally, the resulting program and budget recommendations are forwarded to the legislature and communicated to the appropriate executive agencies, other stakeholders, and the public.

Budget recommendations are reviewed by the Washington State Legislature, including confirmation of revenue forecasts to fund the transportation programs. Separate reviews and hearings are conducted by the House and the Senate Transportation Committees, respectively. Either committee may adjust the proposed list of projects or the amount of funding requested in any of the programs. One or both committees may file a budget bill, which proceeds through the legislative process to final passage and submittal to the governor for signature. The governor may sign the bill as is, veto selected line items, or veto the entire bill, returning it to the legislature for further action. After the transportation budget is passed and signed, CPDM works with WSDOT's Budget Services Office to communicate legislative authorizations and funded items internally to WSDOT regional managers and modal system managers, enabling final adjustments to lists of projects and related tracking-system data. Baselines are established for monitoring subsequent project delivery at the regional and headquarters levels. These baseline data are also incorporated within the legislature's computerized tracking system and WSDOT's Transportation Executive Information System, enabling the legislature and department executives to monitor progress in delivering WSDOT's transportation programs ("Building the Capital Program" Feb. 2008).

Programming Safety Projects

In May 2005, AASHTO presented WSDOT with its newly established Safety Leadership Award, recognizing the department's "proactive approach to safety":

> This approach involved [a] local, corridor, and system-wide perspective. Working with other safety agencies, WSDOT adopted a strategic safety plan, called Target Zero. As an outcome, the state has had a 56% decrease in fatal and disabling crash rates since 1990 even though vehicle miles traveled over that period have increased by 35%. *Source: Measures, Markers, and Mileposts: The Gray Notebook,* Quarter Ending June 30, 2005, p. 52.

Washington State has continued to apply its management, planning, engineering, data collection, and analytic resources to identify and apply cost-effective measures that reduce the societal costs of fatal and disabling crashes. The approach is holistic in that a number of Washington's highway programs and subprograms have measurable safety-related objectives. These objectives consider historical experience; for example, highway locations/sections that have a serious accident

TABLE 9
MP3 WORKSHEET DESCRIPTIONS

Worksheet	Description	Required Inputs/Actions	Optional Inputs	Notes/Comments
Software Notes	Provides software's purpose, structure, color coding scheme. Describes each of the worksheets.	None	None	None
Project Description	Project description	Project description, including route, posted speed, title, beginning and ending mileposts, no build and build number of lanes, and terrain	None	The default population density is taken from the Global Variables worksheet. Posted speeds are rounded to 50, 60, or 70 mph.
Global Variables	Benefit–cost analysis assumptions and default values that are used throughout the workbook.	Discount rate (*i*), project life cycle (*n*), benefit days per year, select or define ADT 24-h distribution curve, identify start and end of a.m. and p.m. peak periods, value of time and operating costs, population density (urban or rural)	Project-specific peak and/or off-peak AVOs. Can provide ratio of benefits to new users (default assumes economic "rule of half")	Defaults should be used unless there is a compelling reason to do otherwise. Any modifications to the default values need to be documented.
24-Hour Volume Distribution Chart	Graphically displays the selected Year 1 directional and total volume distribution by hour of the day	Select or define the ADT 24-h distribution curve in the Global Variables worksheet. The selected curve will automatically be displayed in the 24 Hour Volume Distribution chart	None	Graph only displays the selected Year 1 curve.
Estimate and B-C Ratio	Cost estimates for preliminary engineering, environmental retrofit, right-of-way, construction, operation & maintenance. Incorporates present value of user benefits for each particular improvement. Estimates the benefit/cost ratio.	Quantities needed for cost calculations, non-WSDOT cost share, and operation & maintenance costs, or total WSDOT present value costs (PVc)	User has the option of entering general cost per mile estimates, or a resultant total WSDOT present value cost (PVc) estimated outside of the worksheet.	Can use general cost per mile calculations or detailed cost calculations Output from this worksheet is used as inputs to TOPSIS to prioritize highway mobility projects.
4-Step Model Benefits	Estimates annual 24-h user benefits based on output from an accepted 4-step model.	Model description, truck percent, peak period AVOs, and 24-h vehicle-hours traveled on state facilities	24-h vehicle-hours traveled on entire system, not just state system.	Can estimate user benefits for entire system if data are provided, but only benefits for state system users will be incorporated into overall project B/C ratio.
Two-Way Left-Turn Lane (TWLTL) and Multilane Access Management Benefits	Estimates annual 24-h user benefits for converting a 2-lane undivided facility to a 3-lane TWLTL facility (Harwood/St. John method), or for median treatments and/or access spacing changes for 4–7 lane facilities (*NCHRP 395* method).	Peak direction of selected ADT hourly distribution curve, median type, average access spacing, access control class, daily and peak hour traffic data, and truck %	Peak and nonpeak turns per access, if evaluating benefits using the *NCHRP 395* method.	Uses ADT hourly distribution curve selected in Global Variables to estimate peak and off-peak percents and to convert working peak hour user benefits to 24-h benefits.
General Purpose Lane Benefits	Estimates annual 24-h user benefits for adding a general purpose lane. Facilities that can be analyzed include: a 2-lane highway, an arterial, a rural/small urban freeway, or a multilane highway or freeway.	No build and build posted speeds, direction(s) of added lane, ADT and K factor or working peak hour volumes, truck percent, grade and length of grade, volume growth rate, and roadway type	ADT and K factor or working peak hour volume is required, but either can be input. Can input data for one or two directions.	Benefits are estimated by each hour of the day for the selected direction(s) of the facility.
Climbing Lane Benefits	Estimates the annual 24-h user benefits for adding a truck climbing lane to a 2-lane highway or to an arterial.	Same as above	Same as above	This worksheet has not been updated to look up values from the WSDOT speed-flow curve worksheet. WSDOT curves are embedded in worksheet.

TABLE 9
(*continued*)

Worksheet	Description	Required Inputs/Actions	Optional Inputs	Notes/Comments
Intersection Benefits	Estimates the annual 24-h user benefits for improving an existing intersection	No build and build total approach volumes, number of lanes, average intersection delays, and intersection v/c ratios, existing approach volumes by hour for 24-h, and build scenario percent reduction by approach	Most recent counts of hourly approach volumes that can be converted to existing hourly approach volumes	Benefits are estimated by each hour of the day. Since Year 20 VHT can be higher than Year 1 VHT, there is a potential for negative benefits. When negative benefits are estimated, they are assumed to be zero benefits.
New Interchange Benefits	Estimates the annual 24-h user benefits for adding a new interchange to an existing facility	Year 1 and Year 20 working peak hour volumes, distances and speeds or travel times for no build and build origin–destination (O-D) paths	Model travel times can be input for specific O-D paths instead of being calculated based on distances and speeds.	Working peak hour user benefits are converted to 24-h benefits using ADT hourly distribution curve selected in Global Variables.
HOV Lane Benefits	Estimates the directional annual 24-h user benefits for adding an HOV lane	Directional number of lanes with and without project, ADT or directional working peak hour volumes, HOV and GP growth rates, truck percentages, and traffic composition	Can select the *HCM 2000* speed-flow curve instead of using the WSDOT default curves. Can change default GP/HOV capacities per lane, but must document.	Benefits are estimated by each hour of the day for the selected direction(s) of the facility. Worksheet assumes that HOV lane can be used by GP traffic outside of the peak period.
Park & Ride Lot Benefits	Estimates the bi-directional annual 24-h user benefits for constructing a park & ride lot.	Number of parking spaces, percent of lot capacity used, various destination data, user distribution (transit riders/carpoolers), and AVOs	None	24-h benefits are assumed to be equal to working peak hour or peak period benefits.
Safety Benefits	Estimates the annual 24-h user benefits of improving the safety of a facility.	Selection of safety improvements, identification of the number of accidents by type of accident	None	None
WSDOT Default Curves	Contains WSDOT default speed-flow curves for 50, 60, and 70 mph facilities. Speeds are dependent on v/c ratio and the number of lanes. HOV lane speeds are dependent upon volumes.	None	None	The lowest allowed congested speed for general purpose lane speeds is 15.2 mph (for v/c ± 1.2). Allowable HOV lane speeds are 55 mph at free-flow down to 40 mph at capacity. HOV lane speeds are solely dependent on lane volumes and an assumed capacity
HCM 2000 Curves	Contains the *HCM 2000* speed-flow curves for freeways. Speeds are dependent on free-flow speeds, length of segment, and v/c ratio.	Posted speed and length of section must be provided in the Project Description worksheet. These values are used to estimate speed-flow relationship.	None	Freeway speeds for GP and HOV lanes can range from free-flow speeds down to about 12 mph at a v/c of 2.0.

Source: WSDOT MP3 workbook, "Software Notes" tab (2009).

history—as well as proactive analyses of highway characteristics and traffic volumes and behaviors that point to a potential for accidents in the future ("Safety Management System" Oct. 2009). WSDOT's highway system Preservation (P), Improvement (I), and Maintenance (M) programs all play a role in promoting highway safety. However, this case example will focus specifically on projects included in the Safety improvement (I2) subprogram. Although a number of state DOTs use economic dollar values in analyzing accident costs and conduct safety-related benefit–cost studies, WSDOT's approach is unique in the way it has organized the leadership of statewide highway safety initiatives, including coordination with other agencies and stakeholders.

Role of Economic Analysis in Highway Safety Investment

The computation of the societal costs of accidents (or the benefits of avoiding these costs) is based on the following (*Median Treatment Study* . . . Mar. 2002):

- Identification of the societal costs of different severities of accident: cost per fatal collision, cost per disabling (or serious) injury collision, cost per evident injury collision, cost per possible injury collision, and cost per property-damage-only collision.
- Identification of the frequency of occurrence of each category of accident severity, before and after a particular

safety action (e.g., a safety project, enforcement activity, or educational campaign).
- Computation of benefits in terms of the reduction in accident societal costs resulting from the safety action (whether a reduction in accident frequency, accident severity, or both), comparing the "before" and "after" cases with the yearly benefits discounted through an analysis period.
- Computation of costs of performing the safety action (typically construction plus maintenance) with the annual costs discounted through the analysis period.
- Computation of the benefit–cost ratio, using the discounted values.

Although the B/C ratio is computationally straightforward, predicting accident frequency and severity that result from a safety investment can be difficult. Technical studies such as those described here provide a basis for estimation. Similarly, valuing the societal costs of an accident involves a number of assumptions; cost- and benefit-related issues and a synthesis of state DOT practices are discussed by Hanley (2004). In its safety analyses, WSDOT uses societal costs recommended by FHWA (*2007–2026 Highway System Plan* . . . Dec. 2007).

Legislative Guidance and Agency Goals

WSDOT's highway-safety approach responds to the provisions of the federal SAFETEA-LU legislation (P.L. 109-59, Aug. 10, 2005). SAFETEA-LU establishes and funds the Highway Safety Improvement Program as a core program, giving states flexibility to address their most critical safety needs with a focus on demonstrating performance. It calls for states to develop Strategic Highway Safety Plans (SHSPs), approved by the governor or a responsible state agency, to identify safety needs and opportunities, propose ways to address them through prioritized actions, and evaluate the quality of data. To conform to the provisions of SAFETEA-LU, the SHSP is developed in consultation with others involved in highway safety. It specifies performance-based goals for meeting highway safety needs in both the infrastructural and the driver behavioral categories on all public roads, proposes ways to assess resulting improvement in safety performance, and applies these lessons to prioritizing future safety actions (SAFETEA-LU Aug. 10, 2005).

WSDOT's SHSP is embodied in the *Target Zero* document mentioned earlier, currently updated to 2010 [(*Target Zero*) *Washington State's Strategic Highway Safety Plan* . . . Aug. 27, 2010]. This strategic safety plan sets the important aspirational goal of zero traffic deaths and serious injuries on Washington State's roads by 2030. Consultation in developing this SHSP has included a number of state agencies: WSDOT; State Patrol; Departments of Health, Licensing, and Social and Health Services; Washington Traffic Safety Commission; Washington Transportation Commission and a host of others; several federal agencies; tribal nations and organizations; private and nonprofit groups; and community, local, and regional agencies and organizations. The plan encompasses the "four Es" commonly associated with highway safety programs: engineering, education, emergency services, and enforcement. Key elements of *Target Zero* are incorporated within WSDOT's 20-year Highway System Plan.

The SHSP indicates that fatal highway accidents have declined in Washington State from a rate of 4.91 deaths per 100 million vehicle-miles traveled (MVMT) in 1966 to 0.94 per 100 MVMT in 2008, the state's lowest traffic fatality rate on record and below the 1.27 per 100 MVMT national rate computed by NHTSA (*Target Zero,* p. 7). Several likely reasons for this decline in fatal crashes are cited, including decreased levels of driving resulting from escalating gasoline prices and the economic recession in 2008; investments in cost-effective, performance-enhancing safety projects; improvements in roadway engineering, specific roadside safety features (discussed in greater detail later), vehicle design, and safety equipment; and the beneficial effects of safety education, tougher impaired-driver and seat-belt-use laws, faster emergency response, and law enforcement. Notwithstanding these improvements, challenges to meeting the *Target Zero* goals remain. For example, motorcycle deaths are increasing, countering the otherwise favorable motorist fatality trend. Although impaired-driver-related fatalities are decreasing, they are not dropping fast enough to meet the 2030 zero-level target. WSDOT has adjusted its proposed safety countermeasures to address these issues.

Target Zero organizes the factors involved in traffic fatalities, related safety analyses, and resulting recommendations within four priority levels. For the 2010 update, these priority levels are based on recorded percentages of total highway fatalities during 2006–2008, as follows (*Target Zero,* pp. 11–14):

- **Priority One** consists of factors implicated in 40% or more of traffic fatalities between 2006 and 2008. It includes accidents involving alcohol- or drug-impaired drivers, speeding, and run-off-the-road crashes. Each of these factors was identified as a contributing circumstance in accidents accounting for 40% or more of total highway fatalities. (Author's note: in structuring these priority levels, the *number of fatalities,* not the number of fatal crashes, is used.)
- **Priority Two** consists of factors implicated in 21% to 39% of traffic fatalities in 2006–2008. It includes accidents involving young drivers (ages 16–20 and 21–25), unrestrained passenger vehicle occupants, distracted drivers, and accidents at intersections.
- **Priority Three** consists of factors implicated in 11% to 20% of traffic fatalities in 2006–2008. It includes accidents involving unlicensed drivers; opposite-direction, multi-vehicle collisions; motorcyclists; pedestrians; and heavy trucks.
- **Priority Four** consists of factors implicated in less than 10% of traffic fatalities in 2006–2008. It includes accidents involving older drivers, drowsy drivers, nonmotorized cyclists, road work zones, wildlife, vehicle–train collisions, school buses, and aggressive drivers.

Target Zero notes that many fatalities are associated with more than one of these factors. These traffic deaths are therefore represented more than once in the fatality data associated with the four priority levels.

Technical and Organizational Approach

WSDOT, like several other state DOTs, has found that a particularly cost-effective approach to reducing fatal and disabling-injury accidents is to invest in low-cost, systematic safety improvements. WSDOT has focused on centerline rumble strips and cable median barriers on its mainline state highways as successful ways to manage vehicular departures from the road. Other cost-effective, performance-enhancing safety measures include improvements in (or greater use of) the following: pavement markings (including wider markings, chevrons, and route decals or "horizontal signing"), directional signage, fluorescent yellow sign sheeting (e.g., on curve-warning signs), addition of left-turn lanes, active-warning systems (e.g., for "crossing traffic ahead" and advanced-warning "end-of-green" flashers), roadway lighting, shoulder and edge-line rumble strips, access management (e.g., raised medians), speed-feedback signs, vehicle recovery areas, guardrail end treatments, roadside or guardrail delineators, and features at intersections (e.g., improved vehicular and pedestrian traffic signals, transverse rumble strips, improved signage, and roundabouts). Several state DOT presentations on these types of traffic engineering countermeasures were given at a traffic safety summit ("EveryOne Counts" Feb. 2009).

WSDOT's organizational approach to highway safety improvement differs from models used in some other DOTs. In lieu of a designated safety office or safety engineer, WSDOT organized a Highway Safety Issues Group (HSIG) in the 1990s. Co-chaired by the heads of traffic operations and highway design, the HSIG core membership consists of representatives of WSDOT planning, program management, traffic operations, WSDOT regional traffic and design engineers, and the FHWA division office. By its nature, it promotes a team approach and brings multidisciplinary expertise to safety issues. The HSIG undertakes a number of activities, among them identifying areas of potential safety improvement and coordinating the development of safety policies and initiatives on behalf of the department. It may undertake studies such as safety BCAs, recommend applications of departmental safety resources, and review proposed actions submitted by WSDOT management. It acts as a champion for safety. It also can interact effectively with outside groups through the Washington Traffic Safety Commission (WTSC) (Mercer Consulting Group June 2007, pp. 6–7; *State of Alaska* . . . Sep. 2007, p. E-15).

Safety Program Methods and Measures

WSDOT's assignment of Priority One to run-off-the-road crashes and its emphasis on centerline rumble strips and cable median barriers as technically and economically feasible solutions resulted from nationwide data and analyses that were conducted in the 1990s and early 2000s. A key influence on WSDOT's thinking was a study by the Insurance Institute for Highway Safety, or IIHS (Persaud et al. 2003). The IIHS report compiled available data and research findings from several sources, including FHWA, NHTSA, state DOTs, and academic and consultant researchers, all within the 1990s–early 2000s time frame. These research results collectively indicated the following (Persaud et al. 2003, pp. 1–3):

- Although urban areas experience the highest rates of motor vehicle accidents overall, fatal accidents are more likely to occur in rural areas (2.3 fatal crashes per 100 MVMT on rural highways versus 1.0 fatal crash per 100 MVMT on urban highways nationally).
- Reasons for the higher average rate of severe accidents on rural roads include generally higher traffic speeds, lower seat belt use, longer response times for emergency medical assistance, and road design characteristics, particularly on rural two-lane roads.
- Nationally, rural two-lane roads account for approximately 90% of all fatal crashes on rural highways. The characteristically undivided configuration of two-lane highways, and the absence of wide medians or centerline barriers to physically separate opposing-traffic flows, are factors in vehicles crossing the centerline.
- The result of vehicles departing from their correct directional lanes can be head-on collisions or the sideswiping of vehicles traveling in the opposite direction. Although these collisions are not the result of a single cause, factors typically cited by police include failure to keep in the proper lane, driver inattention, driver fatigue, and speeding.
- Roadway widening and installation of centerline barriers are possible highway engineering solutions to reduce opposing-traffic collisions; however, they are expensive and therefore tend to be limited to specific, high-priority locations. Such spot-location fixes do not solve the more general problem of opposing-traffic collisions that can occur virtually anywhere along the length of a two-lane, undivided highway.
- A more economical and practical potential solution is the installation of centerline rumble strips along the length of undivided two-lane highways. By providing an audible vibration under vehicles encroaching on the centerline, rumble strips can alert inattentive, fatigued, distracted, or speeding drivers that they are drifting into the opposite lane.
- Rumble strips had already proven themselves on the right-hand shoulders of limited access highways in reducing run-off-the-road-to-the-right incidents, which did not involve collisions with opposing traffic. However, at the time of the IIHS study (2003), there was relatively little research or field experience on how these rumble strips would perform on the centerlines of two-lane rural highways. The limited information that was available, however, comprising simple before–after comparisons of crash rates in studies

by two state DOTs, indicated that centerline rumble strips did reduce the rates of both head-on collisions and opposing-direction sideswipes.

- The purpose of the IIHS study was to update these findings on the value of centerline rumble strips in improving rural highway safety. It did this by expanding the available data to a larger pool of state DOT experience, and refining the analysis of crash reductions resulting from centerline rumble strips to correct for certain mathematical algorithms and biases in earlier works.
- The results of the 2003 IIHS study indicated that centerline rumble strips did indeed result in significant crash reductions on two-lane rural highways. All injury crashes combined (i.e., disabling injury, evident injury, and possible injury) were reduced by an average of 15%, or a range of 5% to 25% at the 95% confidence interval. Head-on (frontal) crashes and opposing-direction sideswipe crashes were reduced by an average 25% (5% to 45% at a 95% confidence interval). The study concluded:

> In light of their effectiveness and relatively low installation costs, consideration should be given to installing centerline rumble strips more widely on rural two-lane roads to reduce the risk of frontal and opposing-direction sideswipe crashes. *Source:* Persaud et al. 2003.

The evaluation of candidate safety project sites entails a technical diagnosis of problems and potential solutions, plus a BCA to assist in prioritization.

Safety Program Decision Support

Decision-Making Approach

The objective of this study is to identify cost-effective solutions that yield a high rate of return in terms of reducing fatal and serious (or disabling) injury crashes. For a valid analysis, however, the locations, frequencies, and circumstances of fatal and serious-injury accidents must be known. WSDOT relies on a GIS-based safety management reporting system, supported by descriptive accident data provided by the State Patrol, which enables WSDOT managers to identify where serious safety problems exist, what factors are influencing crashes (particularly those of high severity), and what options might provide the best solution. (WSDOT's Transportation Data Office heads a Collision Report Committee that, with the cooperation of the State Patrol, provides for uniform accident reporting across the state.) The GIS-based graphical displays are packed with information that assists highway and traffic engineers in diagnosing crash locations, clusters, and situations. The highway route and the crash-location symbols employ color coding to indicate crash severity, density of clustering, and locations of significant Priority One events. Each accident indication can be expanded to reveal detailed text descriptions of all crashes that have occurred at that location within the specified time frame (which can be multi-year), based on the aforementioned State Patrol reports.

Based on these data, WSDOT can pursue cost-effective solutions that provide the "biggest bang for the buck" in addressing the targeted safety goal. As an illustration for this case example, WSDOT's analysis shows that many fatal accidents are caused by head-on collisions on undivided highways. The GIS reporting system allows WSDOT to pinpoint those highway locations having the greatest concentration of these crashes or of vehicles leaving the road after crossing the centerline and opposing lanes. In lieu of relatively expensive centerline barriers, WSDOT has pursued more economical centerline rumble strips. The BCA described earlier allows WSDOT to identify high-priority segments where the installation of centerline rumble strips is recommended. It is not unusual for B/C ratios in these segments to exceed 100 to 1.

Legislative Review and Approval

This methodology is the foundation of WSDOT's safety program budget recommendations. The recommendations are submitted to the legislature as part of the transportation budget package. The legislature reviews these recommendations and proposed funding levels, and may make adjustments as described earlier in the section on Mobility before sending the approved budget to the governor for signature.

Follow-Up Studies

WSDOT has followed up on this benefit/cost-based prioritization process to determine whether the safety performance results for centerline rumble strips has been effective. (One could also consider economic performance to be reflected in the before–after analysis of crash statistics, because changes in the frequencies of different accident severities underlay the benefit–cost calculation.) The results of this follow-up study could then inform any updates needed in WSDOT's highway design guidance for centerline rumble strips. Findings and conclusions of this study were as follows (Olson et al. Mar. 2011, pp. ix–x):

- The collisions of primary concern when installing centerline rumble strips are crashes with opposing traffic, either frontal (head-on) or sideswipes. The observed before–after results were a 44.6% reduction in All Injury Severities and a 48.6% reduction in Fatal & Serious (Disabling) Injury collisions.
- In this study, this positive performance result held for all ranges of posted speed limits. No particular speed limit (or range of limits) detracted from the reduction in cross-centerline collisions.
- This positive performance result held for all contributing causes to crashes except one: excess speed. An 18.5%

increase in Fatal & Serious Injury crashes occurred when speeding was a contributing cause. For all other contributing causes, rates of both Fatal & Serious Injury crashes and All Injury Severities crashes declined following the installation of centerline rumble strips.

- With respect to horizontal alignment: Cross-centerline collisions decreased by 59.0% on tangent sections and by 26.8% on curves after installing centerline rumble strips. On the curved sections that were studied, the Fatal & Serious Injury crashes that did occur were primarily the result of excess speed or to drivers impaired by alcohol or drugs. Also, there were differences in the resulting accident rates depending on whether the cross-centerline collisions occurred on the inside or the outside of the highway curve.
- Centerline rumble strips were not anticipated to reduce the collision rates for run-off-the-road-to-the-right events, but they did: a 6.9% decline in All Injury Severities crashes and a 19.5% reduction in Fatal & Serious Injury crashes. Although the research team found this result interesting, further investigation as to why this result occurred and how to explain it was judged to be beyond the scope of that study.
- Conclusions: Centerline rumble strips "are an effective, low-cost, low-maintenance countermeasure that significantly reduces the frequency of collisions, regardless of lane/shoulder width, posted speed limit, or any of the other geometric conditions examined." To further the applications of this successful countermeasure, WSDOT planned to conduct a further study of noise aspects to determine where centerline rumble strips could be installed acceptably in residential areas.

Based on the findings of this study, the research team recommended that (1) WSDOT maintain its current guidance on reducing cross-centerline collisions; (2) WSDOT continue installing centerline rumble strips conforming to this guidance; and (3) from the analytic results, future priority might be given to locations with AADT less than 8,000, combined (one-directional) lane plus shoulder widths of 12 to 17 ft, and posted speeds of 45 to 55 mph (Olson et al. 2011).

Extension to Highway System Planning

Strategic View

Reducing congestion is critical to Washington State's people, economy, environment, and quality of life. "Moving Washington" has been formulated as a strategic initiative comprising actions in three broad areas, all of which are needed to improve mobility in major transportation corridors ("Congestion" and "Moving Washington . . ." 2010). WSDOT executives issue guidance to the planning process in terms of these focus areas:

- **Managing demand** entails commuter travel options that promote greater efficiency by reducing the need to drive, particularly to drive alone. There are many possibilities, such as access to convenient bus service, carpooling and vanpooling, telecommuting, and flextime. Other measures include real-time traffic information displayed on variable message signs, which can influence traffic demand to shift to less congested routes.
- **Operating the highway system more efficiently** by improving the functioning of existing roads. This approach includes measures that smooth traffic flow and remove impediments to flow more efficiently, as in responding to accidents.
- **Adding capacity strategically** through informed investment choices by focusing on the worst bottleneck locations. WSDOT notes that such an approach can improve traffic flow on longer segments of highway while remaining within budget constraints.

These strategies are part of the process incorporated in the production of the Highway System Plan. Identifying the most cost-effective options within these strategies and producing a balanced approach to congestion reduction require additional considerations before BCAs are addressed. The WSDOT office of CPDM introduces these additional considerations as screening criteria and by structuring a tiered, incremental approach to defining candidate solutions for further evaluation in the planning process.

Screening and Structuring Potential Solutions

The screening process recognizes that there is insufficient annual funding to achieve free-flow conditions on highways statewide. The goal is therefore to achieve maximum throughput on congested state highways: approximately 2,000 vehicles per hour, at speeds of 42–51 mph, or about 70% to 85% of the posted speed. At speeds below this threshold, the throughput decreases and the highway no longer operates efficiently. A key screen used by WSDOT for assessing mainline highway congestion is to identify locations where peak-hour speed is less than 70% of the posted limit. This is the primary criterion; others, related to bottlenecks, chokepoints, and congested corridors, are described in WSDOT's Highway System Plan (*2007–2026 Highway System Plan . . .* Dec. 2007). Needs identification is accomplished in coordination with the appropriate MPOs or RTPOs. Proposed projects that meet these criteria are advanced to the next step in the planning process. Those that do not yet meet these screening criteria are held in the Highway System Plan database for future consideration should traffic conditions change on these segments or locations.

Another mechanism used by WSDOT to guide project development toward effective and efficient solutions is to apply a tiered, incremental approach in defining projects. In this way, solutions that do not entail large capital expenditures are investigated first; and, new projects build on the improvements accomplished by previous projects, avoiding wasted effort. The project tiers are at three levels (*2007–2026 Highway System Plan* . . . Dec. 2007, p. 70):

- Tier I—low-cost projects with high return on capital investment and short delivery schedules; for example, incident management, ITS, access management, ramp modifications, turn lanes, and intersection improvements.
- Tier II—moderate- to higher-cost improvements that reduce congestion on both highways and affected local roads; for example, improvements to parallel corridors (including local roads), auxiliary lanes, and direct-access ramps.
- Tier III—highest-cost projects that yield corridor-wide benefits; for example, commuter rail, HOV/HOT lanes, additional general-purpose lanes, and interchange modifications.

The incremental aspect of WSDOT's planning process means that proposed mobility solutions in Tier I must be evaluated (unless they already exist on the highway segment under study) before Tier II solutions can be recommended. Proposed mobility solutions in Tier I and Tier II must be evaluated (unless they already exist on the highway segment under study) before Tier III solutions can be recommended. Evaluation of tiered solutions at this step entails an analysis of traffic impacts and performance improvement over 10 or 20 years.

Further Evaluations for Inclusion in System Plan

Once solutions at the appropriate tiers have been identified as candidates they are subjected to a BCA using the MP3 tool. Solutions with favorable benefit–cost results receive further review under additional criteria; for example, impact on current and future needs projections, the degree of improvement in traffic throughput, and the estimated number of years that the solution will last (in terms of throughput speed meeting or exceeding 70% of posted speed). Proposed solutions, refinements of concepts, and the BCA are conducted in cooperation with cognizant MPOs and RTPOs. Those projects judged most favorable are entered in the Highway System Plan database and forwarded to headquarters executives for review and approval. Projects that are judged as not yet meeting criteria for selection are held in the Highway System Plan database for further future analysis ("2011–2030 Highway System Plan . . ." n.d.).

Analytic Tools

The MP3 workbook that was described for project programming is also used to evaluate Mobility solution benefits at the planning stage. Because projects have not yet been scoped, however, prepared cost estimates are not available. WSDOT has therefore developed a Planning Level Cost Estimation tool to estimate costs for projects still at a conceptual level of development. It is based on historical unit price data for key highway construction cost factors, accounting for regional variations and differences in land use and development density within a region. Input data describe the project in terms of characteristics and features of its right-of-way, mainline roadway, intersections and interchanges, crossroads, bridges, retaining walls, noise walls, wetlands, ITS features, and other items. Unit prices are applied to the quantity estimates for these items; assigned prices also account for regional location (Central Puget Sound, Vancouver, Spokane, other parts of the state) and density of local development (rural, suburban, urban, dense urban). Adjustments can be included for preliminary engineering, mobilization, construction engineering, traffic control, and other implementation items, as well as a separate adjustment for uncertainty (Murshed and McCorkhill 2008).

Resources Needed and Other Information

The MP3 workbook and the Planning Level Cost Estimation tool are the primary analytic tools for the BCA at the planning stage. The MP3 workbook and project scoping estimates provide benefit–cost data for project programming. IDAS (ITS Deployment Analysis System) software is used for ITS cost and benefit estimates. WSDOT also applies a number of other software packages for different types of traffic analyses depending on the complexity of the proposed solution ("Requirements for Proposed . . ." n.d.).

WSDOT staff is conversant with economic methods, and apply the information and tools discussed throughout this summary for long-range and biennial planning updates, capital programming, and budget development. The department makes use of academic and consulting experts for tasks such as research, business-process renewal, model/system development, and implementation assistance. For the most part, however, the department assumes responsibility for using these products once completed.

BRIDGE PROJECT PROGRAMMING AND PERMITTING

Introduction

This case describes the methodology applied by Caltrans for bridge project programming, with significant influence on decisions exerted by permitting requirements. Caltrans applies the Pontis™ bridge management system (BMS) for conventional analyses of bridge preservation and mobility improvement, and for decision support in project prioritization. However, a number of critical, risk-related bridge needs are not addressed by a BMS and must be analyzed separately. Moreover, bridge projects in California are potentially subject to permitting requirements or right-of-way negotiations that, experience has shown, can extend several years beyond the time needed for project plan development. The Caltrans Bridge Management Office has therefore developed a unique and innovative approach to evaluating bridge projects for inclusion in its State Highway Operation and Protection Program (SHOPP). This procedure entails the use of utility theory to capture the benefits of reducing risks of degraded bridge performance regarding scour, seismic events, and bridge-railing safety, in addition to benefits associated with meeting the preservation and mobility needs. This computed value of utility is applied as the measure of benefit in a "benefit–cost analysis" (or, perhaps more accurately, a cost-effectiveness analysis structured as a B/C ratio). Cost-effectiveness is not, however, the only decision variable to be considered. The time to obtain permit approval for these bridge projects, particularly in coastal regions and certain other situations, means that the programming decision must consider those projects that realistically can be expected to be ready for construction within a manageable time period. The following descriptions describe Caltrans' analytic procedures for programming of bridge needs, and use of these results in decisions on bridge project recommendations.

Role of Economic Analysis in Highway Investment

Background

With an inventory of just under 13,000 state highway bridges and with bridge needs exceeding annual funding, Caltrans looks to make informed decisions in selecting the "best" projects for its bridge program. The California SHOPP identifies bridge preservation needs in five areas: (1) rehabilitation and replacement owing to deterioration of bridge elements, (2) scour risk reduction, (3) seismic risk reduction, (4) bridge rail upgrade (a safety matter), and (5) mobility upgrades (raising and strengthening structures to accommodate updated traffic volumes and vehicle characteristics). SHOPP lists funding commitments to selected projects through a 4-year programming period. California state law also requires a 10-year SHOPP plan that identifies unconstrained needs across all transportation assets. Although BMS analyses, which include economic as well as technical modeling, can address needs for preservation (rehabilitation or replacement) owing to condition-based deterioration of bridge elements and for mobility upgrades, they do not deal effectively with risk-related problems: seismic, scour, and bridge-rail safety. These risk-based needs, which account for about 40% of the total SHOPP bridge-related amount, require different analytic procedures. Caltrans has turned to multi-objective utility theory to represent the benefits of addressing the five categories of bridge needs, with initial application of the procedure to the 2008 SHOPP development (Johnson 2008).

Multi-Objective Utility Model

A dimensionless, multi-objective, zero-to-one utility function represents the contributions of several factors relevant to programming decisions. Moreover, the factors can be weighted to reflect their relative importance. The general utility relationship is given in Eq. 1 (Johnson 2008).

$$U_t = \Sigma a_i b_i X_i = a_1 b_1 X_1 + a_2 b_2 X_2 + a_3 b_3 X_3 + a_4 b_4 X_4 + a_5 b_5 X_5 \qquad (1)$$

where:

- U_t = total project utility, zero to one;
- Σ = sum for all $i = 1$ to 5;
- a_i = indicator that attribute i is addressed (1 = yes, 0 = no), $i = 1$ to 5 denoting each category of bridge needs;
- b_i = weighting factor for attribute i; sum of all weighting factors = 1.0;
- X_i = value function of attribute i contributing to the utility function, where:
  - X_1 = value function for bridge rehabilitation or replacement;
  - X_2 = value function for scour risk mitigation;
  - X_3 = value function for bridge rail upgrade;
  - X_4 = value function for seismic risk mitigation; and
  - X_5 = value function for bridge mobility improvement (strengthening and raising clearances).

Example for Scour

The individual value functions X_i are themselves relationships containing dependent and independent variables, coefficients, and functions. For example, in terms of the National Bridge Inventory (NBI) rating items, the scour-related contribution to utility (i.e., the value function X_2) is formulated using the NBI scour item (Item 113), the average daily traffic (ADT, Item 029), and detour length (DL, Item 019) (*Recording and Coding Guide* . . . Dec. 1995). Ratings of condition within the NBI are assigned on a 0 to 9 scale, where 9 denotes "undamaged" or "not subject to risk," 3 denotes "critical," and 0 denotes "bridge failed, out of service." As an example, consider the scour value function X_2, with a form expressed in Eq. 2. This function is graphed in Figure 2 versus the NBI scour rating code *SC,* with values of traffic *ADT* and detour length *DL* held constant. The value-function results are interpreted as follows (Johnson 2008, pp. 191–192):

- When $SC = 8$, the bridge foundation is "stable" and the scour risk is essentially zero. A project that addresses scour would therefore provide no real benefit in terms of scour risk mitigation. (An NBI rating of 9 for this item would denote a bridge foundation on dry land, well above flood water elevation, and is not represented in the value function.)
- As the scour risk increases (i.e., as *SC* moves toward the "critical" threshold where the scour rating would equal 3), the scour value function likewise increases and at $SC = 3$ it exceeds 0.75. Projects that mitigate scour risk now are in a range to contribute substantial potential benefit to the utility function.

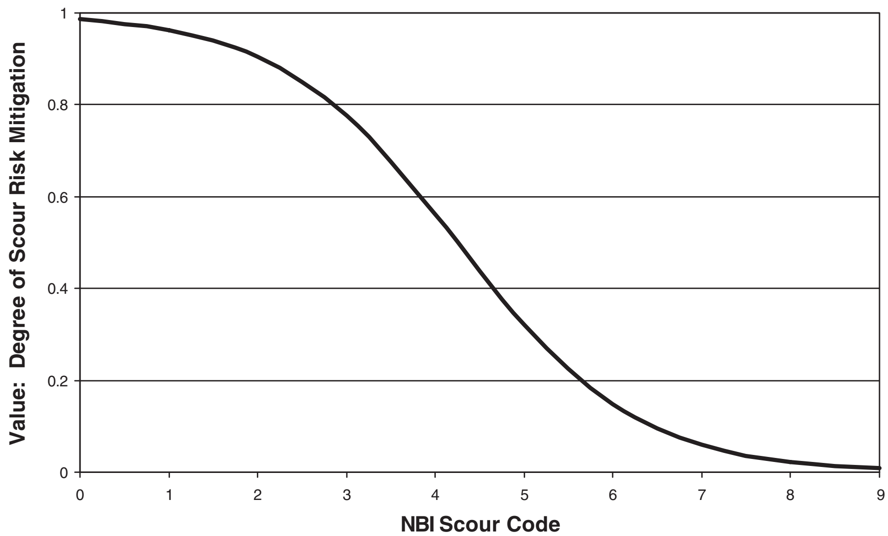


FIGURE 2 Example value function for scour risk mitigation, X_2.

$$X_2 = 1 \Big/ \Big[1 + \exp \Big[- \begin{pmatrix} -4 + (8 - SC) \\ + 0.000001 * ADT * DL \end{pmatrix} \Big] \Big] \qquad (2)$$

where:

X_2 = the value function for scour risk mitigation;
SC = the NBI scour rating code, Item 113, for a bridge;
ADT = the average daily traffic, NBI rating Item 029; and
DL = the detour length around the bridge, miles, rating Item 019.

Generalized Value Functions for Bridges

To generalize the scour example to the other utility attributes (i.e., the other categories of bridge needs), all of the value functions are expressed as a logit, or "S-shaped," function given in general form in Eq. 3 (Robert and Vlahos 2007, cited by Johnson 2008, p. 191). The specific relationships governing the value functions of all categories of bridge needs are shown in Table 10, together with explanations of parameters and the values of assigned weights. In developing these relationships and weights, Caltrans bridge engineers

TABLE 10
CALTRANS VALUE-FUNCTION ELEMENTS FOR FIVE CATEGORIES OF BRIDGE NEEDS

Attribute = Category of Bridge Need	Key Parameters		Expression for $C(i)$ in Eq. 3	Assigned Weight
i = 1: Rehabilitation and replacement needs	BHI ΔBHI TEV ADT DL RU	Bridge Health Index Change in BHI Due to Project Total Element Value in Bridge Average Daily Traffic Detour Length Around Bridge Repair Urgency	$-2.5 + 0.000001[(100 - BHI - \Delta BHI) * TEV]/100 + 0.00000001 * ADT * DL + 0.5 * (10 - RU)$	25%
i = 2: Scour needs	SC ADT DL	NBI Scour Code Average Daily Traffic Detour Length Around Bridge	$-4 + (8 - SC) + 0.000001 * ADT * DL$	20%
i = 3: Bridge-rail upgrade needs	RS	Caltrans Bridge–Rail Upgrade Score	$-2 + RS$	10%
i = 4: Seismic retrofit needs	Sv ADT DL	Caltrans Seismic Priority Average Daily Traffic Detour Length Around Bridge	$-1.5 + Sv + 0.000001 * ADT * DL$	25%
i = 5: Mobility needs (raising/strengthening)	PIB	Pontis Improvement Benefit	$-4.5 + 0.00015 * PIB$	20%

Source: Johnson (2008), Tables 1 and 2.
Note: Author has changed some variable names slightly to increase comprehension.

sought to incorporate the set of key decision variables, draw on readily available bridge condition and rating information, and predict individual bridge-needs benefit values (X_i) and overall project utility (U_t) that would reflect the judgments of experienced bridge engineers. Trial use of the methodology and sensitivity analyses confirmed that individual value functions and total improvements in utility correlated highly with project priorities that would have been assigned by experienced bridge engineers. The utility approach that is based on Eq. 1 has enabled Caltrans to analyze the programming of bridge projects across the diverse categories of bridge needs simultaneously, and to reflect the overall benefit of a project within a single utility value U_t (Johnson 2008, pp. 191–194).

$$X_i = 1 \Big/ \left[1 + \exp\left(-C\left(i\right)\right)\right] \quad (3)$$

where:

X_i = the value function for attribute i, $i = 1$ to 5: that is, the value function for each category of bridge needs (refer to Eq. 1);
exp = the exponential function;
$C(i)$ = exponent for each attribute i, given in Table 10 (note that the negative of this value must be used in Eq. 3).

Values of these parameters are obtained from one of the following sources: NBI bridge ratings conducted by Caltrans according to the NBI Coding Guide (*Recording and Coding Guide* . . . Dec. 1995); departmental calculations of factors such as the BHI (Shepard and Johnson 2001), seismic retrofit priority *Sv,* and bridge rail upgrade score *RS*; the improvement-related benefit of projects, Pontis Improvement Benefit, as analyzed by the Pontis BMS used by Caltrans (technical reference: Cambridge Systematics, Inc. 2005); and the Total Element Value (TEV) of a bridge as defined in Caltrans' bridge health index (BHI) formulas (Shepard and Johnson 2001), computed by Pontis as documented in its technical reference (Cambridge Systematics, Inc. 2005). An additional use of the TEV is explained in the following section.

Methods and Measures

Adjustment for Project Scale

In applying the utility concept as a generalized measure of benefit for comparison to cost Caltrans realized one other adjustment was needed. The cost of a bridge project is influenced by many factors, but an important one is the scale or magnitude of the project, which is related to the size or value of the existing bridge. Given this dependence of cost on bridge scale, it was necessary to compensate on the benefit side to provide a fair assessment of benefit (or utility) to cost, bearing in mind that the utility is a dimensionless, zero-to-one number that does not retain any information on project scale. (This discussion applies to risk mitigation, but not necessarily to bridge rehabilitation work. Although risk mitigation is blind to bridge size, bridge rehabilitation considerations by Caltrans make use of a BHI, which does account for the relative size of the structure.) Among several possibilities for accounting for bridge scale, Caltrans selected the TEV parameter described in Table 10. The final measure of "benefit–cost," or measure of cost-effectiveness structured such as a benefit–cost ratio, is given in Eq. 4.

$$\text{Project Utility B/C ratio} = U_t{*}TEV \big/ \text{Project\_Cost} \quad (4)$$

where all benefits variables are as defined earlier, and Project_Cost is the cost of the proposed project developed by Caltrans' Office of Specialty Investigations & Bridge Management as part of its SHOPP program building.

Illustration of Utility as a Benefit Measure for Bridges

A simple arithmetic example illustrates how the U_t benefit measure operates to distinguish relative benefits of projects on different bridges, a key step in project programming (Johnson 2008, p. 193). The example includes both a condition-related need (rehabilitation and replacement) and a risk-related need (mitigation of scour-related risk); a combination that Caltrans believes demonstrates the power of the utility concept. Consider two bridges with similar structures but with different combinations of condition and scour needs, as shown in Table 11. Assume two projects for bridges A and B, respectively that address both condition and scour needs.

- Bridge A has ratings that indicate a condition-related value (X_1) of 0.20. Its NBI scour rating is 8, which denotes no scour ($X_2 = 0$; refer to Figure 2). The contribution of these values to the project utility computed for Bridge A is shown in the last column of Table 11 to be 0.05, using the weights for condition and scour in Table 10.

TABLE 11
EXAMPLE OF THE UTILITY CONCEPT APPLIED TO TWO BRIDGES

Structure	Condition Value, X_1	NBI Rating of Scour Risk (Item 113)	Scour Value, X_2	Contribution to Utility U_t (weighted sum of X_1 and X_2)
Bridge A	0.20	8: no scour	0.0	0.25 * 0.20 + 0.20 * 0.0 = 0.05
Bridge B	0.20	3: scour is critical	0.75	0.25 * 0.20 + 0.20 * 0.75 = 0.20

- Bridge B also has ratings that indicate a condition value $X_1 = 0.20$. Its NBI scour rating however is 3 (critical), which corresponds to a scour value X_2 of 0.75 (Figure 2). The contribution of these values to the utility of the project for Bridge B is 0.20, or four times the benefit value for Bridge A.

The Caltrans Bridge Management Office has applied the set of value functions and weights to every state-owned bridge in the BMS, together with estimated project costs. Those bridges with the highest utility–cost ratios (Eq. 4) were evaluated for possible inclusion in the SHOPP program. This exercise showed that the approach can be used successfully for an inventory of bridges of different size, material, and composition.

Possible Future Modifications

Caltrans noted a simplifying assumption in this initial development of a utility approach. It was assumed that the post-project condition and risk value functions would all be restored to an undamaged ("like new") or no-risk state. This assumption was justified partly by a tenet of the SHOPP program: all needs should be addressed when a SHOPP project is undertaken. A possible future refinement is to reflect the relative effectiveness of different bridge treatments, in which the post-project value functions do not automatically assume complete correction of damage or complete removal of risk. (Although not discussed in the Caltrans paper, this refinement could also be a first step to representing a time dimension more explicitly within the total utility result.)

Decision Support

A multi-step process is used to evaluate candidate bridge projects for SHOPP and to build a prioritized program, a process comprising the following steps:

- A bridge inspection or an analysis of the bridge identifies bridge needs.
- For bridge replacement needs or for needs that exceed a certain cost threshold, a peer review is required by internal Caltrans policy. The peer review, conducted by Structure Maintenance & Investigations personnel, documents the following: current issues with the bridge structure and materials performance, alternatives considered for solving the problems, LCCAs that have been performed to compare these alternatives, and notes of remaining concerns.
- The result of the peer review is a recommended strategy to deal with the identified problems on the bridge, organized within a project.
- A utility function is developed for each competing bridge need or proposed project, formulated as described in the previous section. A utility–cost ratio is computed (Eq. 4).
- The utility–cost ratios are used to create an initial ordering of bridge priorities for purposes of planning.
- More complete project data are developed in project study reports. These data are evaluated to further assess the project's priority and its likelihood of being delivered on schedule.
- Depending on the result of this assessment, funds may be allocated to the project. Alternately, the project may be developed further without additional funding allocation, until its likelihood of timely delivery improves.

This issue of project delivery is a significant one for Caltrans regarding bridge projects generally, and especially those projects in coastal zones or sensitive environmental areas, and those projects involving historic bridges. Internal Caltrans reviews have shown that (1) bridge projects are much more likely to require substantial environmental study than are highway projects generally; (2) the time needed to complete an environmental review for bridge projects averages 4 years for a Finding of No Significant Impact, and 8 years for an Environmental Impact Study—both of which exceed the 4-year time frame of a given SHOPP program document; (3) the time needed to complete an environmental review for bridge projects is longest for bridges requiring Coastal Zone Conservation clearances, regardless of the type of environmental document required; for example, the average time to complete an Environment Impact Study in this case is almost 11 years; and (4) the type of bridge work and its setting (e.g., whether over water) also affect the environmental clearance time—bridge widening and bridge replacement projects are typically the most problematic.

Resources Required and Other Information

Resources

- Application of the utility-based approach to programming is performed by Caltrans staff.
- Consultants assisted in developing the initial concepts and models.
- The analytic tools needed are relatively simple; value-function calculations and their contributions to total utility can be handled in spreadsheet workbooks.
- Data of the required currency, accuracy, and timeliness are generated through the federally mandated biennial bridge inspection program, the peer reviews that are conducted for certain bridge projects, and routine activities performed as part of the programming process, such as preparation of cost estimates.
- Caltrans has been a leader in promoting EEA within a wide range of departmental activities and analyses. Members of the department's bridge unit served on the state-user advisory panel that assisted in the original development of the Pontis BMS. The agency has also developed detailed BCA products, the Cal-B/C series, for use at a project, corridor, or network level. Cal-B/C is applied in a later case example on Value Analysis (Caltrans' implementation of VE).

- Caltrans has an extensive organizational commitment and website resources dedicated to a wide range of topics in EEA. Among these topics are LCCA and BCA, supported by drill-down details on individual website pages to address each step of an analytic procedure and to explain the application of the correct method to particular cases or situations. There is strong integration of economic concepts and methods within a number of Caltrans business processes, buttressed by comprehensive and detailed documentation.

ECONOMICS-BASED TRADEOFF ANALYSIS

Introduction

In its consideration of asset management systems for transportation infrastructure, the New York State DOT (NYSDOT) has sought to articulate the distinctive aspects of an "asset management approach" as compared with that of traditional infrastructure management systems. Several precepts that distinguish asset management have been identified to guide system design and development. A core capability in this approach is the conduct of tradeoff analyses among four major departmental programs or "goal areas": pavements, bridges, safety, and mobility. To address a well-known stumbling block in analyzing such tradeoffs—the need for a common measure of benefit across different programs or projects—NYSDOT has looked to an economics-based measure, excess road user costs. Based on this concept, a prototype tradeoff analysis has been developed. Although this experimental procedure has not yet been implemented on an operational basis, it has been included in these case examples to illustrate a unique and innovative application of EEA. Within the framework established for this synthesis, this case example addresses programming or resource allocation at the highway corridor and network levels, affecting investments across multiple programs.

Role of Economic Analysis in Highway Investment

This case example of a tradeoff analysis prototype is drawn from materials prepared by NYSDOT asset management staff: a paper published through TRB (Shufon and Adams 2003) and a slide presentation at the Fifth National Transportation Asset Management Workshop (Adams 2003). Summary information on this presentation in the context of other workshop discussions is given in the workshop proceedings (Wittwer et al. 2004). Further background information on the NYSDOT tradeoff analysis concept has been compiled by FHWA in its asset management case study series ("Economics in Asset Management: The New York Experience" 2003).

Asset Management Framework

In their consideration of the distinguishing features of asset management that could provide value-added information and insights, NYSDOT managers realized the following (Shufon and Adams 2003):

- Traditional management approaches were organized vertically within each program or goal area (pavement management, bridge management, safety management, mobility or congestion management). These vertical perspectives, often referred to as "stovepipes" or "silos," enabled basic infrastructure data (e.g., inventory, current and historical condition, and performance) to be transformed into information useful to various business processes at different organizational levels: identification of investment needs, planning, programming, budgeting, and so forth.
- To provide additional benefits, an asset management system needed to go beyond these capabilities of existing or legacy management systems; for example, an updated system architecture, advances in data collection techniques, improved database design, or other advances that enabled better decisions based on better information. Lacking any beneficial contribution, "asset management systems" would simply represent the "buzzwords du jour."
- Although a vertical perspective on infrastructure management processes was still needed, asset management also called for a horizontal consideration across programs or goal areas. This view would enable managers to consider multiple assets and the tradeoffs inherent in balancing investment choices among them. A tradeoff analysis would integrate highway infrastructure decisions and provide a greater benefit to users. (Multimodal tradeoffs have also been addressed in the asset management literature, but are not the focus of this synthesis.)

These perspectives led NYSDOT managers to articulate the contributions of an asset management system within the following four precepts:

> [1] Asset management systems are decision support systems. They do not make decisions; people make decisions. The business foundation must be in place to support decision making.
>
> [2] It would be virtually impossible to cover all assets owned or administered by a transportation agency. Assets should be covered only by the umbrella asset management system in which trade-offs make sense. For example, it makes little sense to develop procedures for trade-off analysis between investment in pavement preventive maintenance and investment in specialized transit services for the handicapped. In addition, the individual or "silo" management system should be already operational for the asset to be covered by the umbrella system. Otherwise, costs for the inventory, condition assessment, and so forth, would be prohibitive.
>
> [3] Trade-off analysis can be conducted only if a common technical measure can be used to quantify benefits of diverse projects: for example, a pavement project versus a mobility project.
>
> [4] Generally, these analysis methods involve an economic analysis of competing alternatives. *Source:* Shufon and Adams 2003, p. 38.

Common Measures for Diverse Projects: Excess Road User Costs

The third and fourth precepts underlay the application of EEA to tradeoff analyses. The commensurate measures selected by

NYSDOT managers were the excess road user costs associated, respectively, with each of the department's goal areas (or programs). These excess costs were defined as "incremental costs incurred by [highway] users . . . attributed to less than ideal operating conditions" (Shufon and Adams 2003, p. 40). Excess user costs comprised three components: the cost of delays to travelers and freight, accident or crash costs, and VOC. Examples of excess road user costs resulting from less than ideal conditions are the cost of additional tire wear because of rough pavement, the additional trip length (affecting both travel-time cost and vehicle operating expenses) imposed on truck travel owing to a posted bridge, and the cost of an accident that might have been prevented with an improved highway feature. Another way to view these costs is to regard them as "avoidable" costs, which provides the basis for treating them as the benefits of pavement, bridge, or safety-related road improvement projects. The treatment of excess user costs in each goal area is as follows (Shufon and Adams 2003, p. 40).

Pavement-Related Excess User Costs Pavement-related road user costs are related by NYSDOT to the International Roughness Index (IRI). A threshold value of acceptable IRI can be established; the additional road user costs incident to higher IRI values would constitute excess user costs. The department had engaged Cornell University researchers to advise on specific analytic relationships; their recommendation was to adapt pavement management models that had been developed by Saskatchewan. NYSDOT's application of these models quantified the pavement roughness effects on various components of road user costs: fuel, tire, and vehicle parts consumption; labor cost for vehicle repair; delays and diversion of traffic; and damage to cargo. Of these, NYSDOT found that the roughness-related excess user costs for fuel consumption, cargo damage, and delays or diversion were negligible and safely ignored in network analyses of the state-maintained highways. It was recognized that these results might not hold for local roads or other nonstate networks, where IRI values might be higher than on state highways.

Bridge-Related Excess User Costs Excess user costs related to bridges include detour costs (entailing travel time and vehicle operation) borne by truck traffic resulting from inadequate bridge and approach clearances and load postings, and accident costs resulting from deficient bridge and approach geometry. NYSDOT staff identified sources of information on these relationships; for example, PONTIS (a software application developed to assist in managing highway bridges and other structures) and research by Florida DOT (FDOT). The department adapted the FDOT models for its bridge-related excess user cost calculation.

Safety-Related Excess User Costs Excess user costs resulting from accidents are derived from concentrations of crash locations, to which roadway characteristics can be a contributing cause. NYSDOT's system for tracking accidents can identify High Accident Locations (HALs), which comprise Priority Investigation Locations and Safety-Deficient Locations.

- Priority Investigation Locations are highway locations at which the accident rate is more than three standard deviations higher than the mean rate for the comparable class of highway.
- Safety-Deficient Locations are highway locations at which the accident rate is one to three standard deviations higher than the comparable mean rate.

The excess user cost associated with HALs is computed as the product of the difference between the accident rate at each high-accident location and the comparable mean rate, and the average cost per accident obtained from NYSDOT accident data tables.

Mobility-Related Excess User Costs Excess user costs related to mobility—that is, congestion costs—arise from both recurring congestion problems and from individual highway incidents. New York State defines congestion as "delay to persons and goods beyond a limit that can be tolerated"—quantitatively, the boundary between Levels of Service D and E. NYSDOT's Congestion Needs Assessment Model can identify congested locations and calculate excess user costs as a function of vehicle hours of delay for both auto passengers and freight. However, NYSDOT has for the time being focused the tradeoff exercise on only the freight portion of these costs. (Computation of passenger values of time is beset by several analytic issues and motorist behavioral assumptions. Delays to freight are currently believed to be more clearly defined and supported analytically, and are more consistent with NYSDOT's current priorities and decision-making practices.)

Methods and Measures

Highway System Levels for Computing Excess User Costs

For each goal area of pavement, bridge, safety, and mobility, NYSDOT computes and assembles the measures of excess road user cost at three highway-system levels:

1. Individual asset: pavement segment, bridge structure, safety-deficient location, and mobility location.
2. Analysis link: length of highway between major intersections, comprising some portion of the individual assets discussed earlier.
3. Corridor: a highway route within a county, comprising some portion of the analysis links discussed earlier.

New York State's highway system consists of a total of 15,000 centerline-miles or 40,000 lane-miles. This system contains approximately 7,000 analysis links and 1,500 corridors.

Tradeoff Measures

Measures used in the tradeoff analysis are structured as a benefit–cost ratio.

- Benefits are defined as reductions in excess road user costs that are attributable to a corrective project. They are excess user costs that are now avoided. These benefits are computed as an annual figure.
- Costs are agency expenditures for the project. To convert costs to an annual basis, the project expenditures are multiplied by a capital recovery factor as a function of the service life of the project and the current departmental discount rate.
- The benefit–cost ratio is computed using the annual benefit divided by the annualized cost. This computation is performed at the asset, link, and corridor levels described in the previous section.

Prototyping Decision Support

Because the NYSDOT research was confined to a prototyping stage, examples of actual decision support are not available. However, departmental staff developed reports that illustrate the type of information that could be made available to decision makers needing a better understanding of investment tradeoffs. Two example reports for a hypothetical highway corridor are shown in Tables 12 and 13:

- Table 12 displays information on excess user costs estimated for each goal area by link in the corridor. In addition to total excess user costs among all goal areas, it includes an estimate of "base" user costs; that is, costs that are not considered "excess." The ratio of excess to base user costs in the rightmost column is an indication of the excess-user-cost "tax" borne by each motorist because of deficiencies in key highway assets in this corridor.
- Table 13 displays the corridor benefit–cost information that would be computed as described in the previous section. The benefit–cost ratios are viewed by NYSDOT as indicators suggesting potential candidates for program investments, warranting further investigation and analysis. It is also the view of NYSDOT staff that "the power of the [benefit–cost] approach is the capability to assess the investment potential for groups of diverse assets taken together, such as links and corridors" (Shufon and Adams 2003, p. 44).

Tables 12 and 13 can be analyzed vertically or horizontally. Vertical comparisons consider potential investments within a program; horizontal comparisons, among programs. NYSDOT personnel also envisioned that results shown in these two tables could be displayed not only by the aggregations of assets shown (individual asset, link, and corridor), but also by other delineations; for example, route, county, functional classification, traffic-volume groupings, or other available parameters. Economic and demographic data would also accompany these analyses, allowing summaries to be prepared, for example, for areas suffering low economic growth, where reduction of excess transportation user costs could be targeted to improve the local economy.

Resources Required and Other Information

Implementation Issues and Challenges

Given its status as a prototyping exercise, this case example has not yet developed a track record of resources to be applied in conducting actual tradeoff analyses. Suffice it to say that the proposed analysis, intended as part of NYSDOT's asset management system for its transportation infrastructure, is

TABLE 12
EXAMPLE EXCESS-USER-COST OUTPUT FOR A CORRIDOR ($000S)

Analysis Link	EUC Pavement	EUC Bridge	EUC Safety	EUC Mobility	Total EUC for Link	Est. Base User Cost	Excess/Base User Cost
L1	50	—	100	—	150	7,000	2.1%
L2	40	40	—	—	80	6,000	1.3%
L3	—	30	—	20	50	3,000	1.7%
L4	—	80	40	30	150	10,000	1.5%
L5	120	100	50	100	370	10,000	3.7%
L6	90	—	60	110	260	10,000	2.6%
Corridor Totals	300	250	250	260	1,060	46,000	2.3%

Source: Shufon and Adams (2003), Figure 6, p. 42.
Notes: EUC = Excess [Highway] User Costs. — = no excess user costs assumed to occur.

TABLE 13
SAMPLE BENEFIT–COST OUTPUT FOR A CORRIDOR (COSTS ANNUALLY IN $000S)

Analysis Link	Pavement			Bridge			Safety			Mobility			Link Totals		
	Annual EUC Avoided	Annual-ized Project Cost	Bene-fit–Cost Ratio	Annual EUC Avoided	Annual-ized Project Cost	Bene-fit–Cost Ratio	Annual EUC Avoided	Annual-ized Project Cost	Bene-fit–Cost Ratio	Annual EUC Avoided	Annual-ized Project Cost	Bene-fit–Cost Ratio	Annual EUC Avoided	Annual-ized Project Cost	Bene-fit–Cost Ratio
L1	50	40	1.2	—	—	—	100	50	2.0	—	—	—	150	90	1.7
L2	40	60	0.7	40	20	2.0	—	—	—	—	—	—	80	80	1.0
L3	—	—	—	30	50	0.6	—	—	—	20	100	0.2	50	150	0.3
L4	—	—	—	80	60	1.3	40	40	1.0	30	20	1.5	150	120	1.3
L5	120	200	0.6	100	80	1.3	50	50	1.0	100	200	0.5	370	530	0.7
L6	90	50	1.8	—	—	—	60	110	0.5	110	100	1.1	260	260	1.0
Corridor Totals	300	350	0.8	250	210	1.2	250	250	1.0	260	420	0.6	1,060	1,230	0.9

Source: Shufon and Adams (2003), Figure 7, p. 43.
Notes: EUC = Excess [Highway] User Costs. — = no excess user costs assumed to occur.

supported by a number of individual management systems and data collection, processing, and analysis activities. The analysis has been conceived by NYSDOT asset management personnel, with the support of university and industry research in the development of component models of asset performance.

The NYSDOT researchers did, however, identify issues that they perceived would be challenges in bringing the tradeoff analysis to actual practice (Shufon and Adams 2003, p. 44):

- The first issue is the availability of realistic agency costs to reduce or eliminate excess road user costs. Pavement and bridge costs are available from pavement management and bridge management systems, respectively. These systems include decision-support algorithms that seek to identify the preferred treatment to address deficient conditions and performance. However, the same is not true for safety and mobility. There is a range of safety and mobility actions to address highway sections exhibiting similar performance (e.g., numbers of HALs or vehicle hours of delay). Specifying preferred treatments within an investment tradeoff analysis, prior to detailed studies of specific site conditions and factors, is complicated. NYSDOT is studying the issue to see if average costs of safety and mobility actions can be estimated for use in the denominator of the B/C calculation.
- The second issue concerns the use of avoided excess highway-user costs as the measure of benefits to compare the worth of projects across diverse programs. "Base costs" and "excess costs" imply a threshold value dividing the two categories; this threshold must be chosen with care. For example, too low a value for a particular program would encourage overinvestment in that program. To counter this tendency, the NYSDOT researchers recommended that the asset management system recommendations, including the tradeoff results, be reviewed by, and calibrated to, "the professional experience of a panel of experts who are responsible for regional program development." These results would then be "presented to NYSDOT executive management for policy guidance."
- The third issue deals with the scope of the proposed analysis, which is at a highway system or network level, and is based on relative performance (avoided excess user costs) rather than asset condition specifically (e.g., pavement, bridge, safety, or operations needs or deficiencies). The implication is that there is still an important need for management systems that address individual assets; for example, pavement management and bridge management systems. The tradeoff analysis relies on these systems for recommended treatment actions and costs, as discussed earlier. Furthermore, these individual asset systems analyze options that are not considered in the tradeoff approach proposed earlier.
  – For example, the tradeoff analysis does not consider preventive maintenance policies that could lengthen life expectancy of pavements now in smooth condition (and which therefore have not yet triggered excess user costs).
  – Nor does the tradeoff analysis consider the penalties of deferred maintenance in terms of the additional future agency cost that will be incurred, for example, by delaying correction of bridge structural deficiencies.

Notwithstanding these limitations, the tradeoff analysis is viewed realistically as an additional decision-support tool that provides comparative information horizontally across highway investment programs as well as vertically within them. As a component of an asset management system, it complements, but does not replace, information available from current systems that manage individual assets.

PAVEMENT TYPE SELECTION

Introduction

The use of LCCA for pavement type selection appears to be one of the more widespread uses of engineering economic methods in the United States, as shown by surveys (including the results obtained for this synthesis) that are presented in chapter two. A case example of this application of economic methods thus helps to identify the characteristics of LCCA use across the United State. Results from recent surveys at a broad level will be used to illustrate nationwide patterns as well as the diversity in selection of key parameters such as discount rate. Discussions will then focus on two particular state DOTs to identify specific policies, methods, and other characteristics of LCCA use. Within the framework of this synthesis, these LCCA applications relate to project-level design and development.

Role of Economic Analysis in Highway Investment

Pavement-Oriented Federal Guidance

The FHWA has issued several guidance documents on the use of LCCA in pavement design and type selection, investment analyses of investments at other stages of the pavement life cycle, and for related purposes such as alternate bidding. For purposes of this case example, the relevant guidance is included in the FHWA's Final Policy Statement ("LCCA Final Policy Statement" Aug. 29, 1996). Information on the engineering aspects of pavement design and performance and how they can be incorporated within life-cycle analyses is given in the FHWA's Technical Bulletin on the subject (*Life Cycle Cost Analysis* . . . Sep. 1998). Through its Final Policy Statement, FHWA supports and encourages the use of LCCA to analyze investment alternatives for pavement design, and outlines principles of good practice that might be followed regardless of the methodology used. Among these principles are the following ("LCCA Final Policy Statement" Aug. 29, 1996):

- Life-cycle costs should be considered in all phases of a pavement's life cycle: construction, maintenance, rehabilitation, and operation.
- Analysis periods should be long enough to capture long-term differences in discounted costs among competing alternatives and rehabilitation strategies. These periods should encompass several maintenance and rehabilitation cycles, and for some pavement designs may include reconstruction as well.
- All significant differences in agency and user costs between alternatives should be considered in the analysis.
- Considerable uncertainties in key aspects of the analysis should be recognized and addressed through quantitative and qualitative assessments such as sensitivity analysis, probabilistic techniques or risk analysis, expert panels, or other mechanisms.
- Streams of agency and user costs through the analysis period should be discounted to net present value (or converted to equivalent uniform annual cost) using discount rates that are consistent with *OMB Circular A-94*.

In a subsequent clarification of FHWA policy regarding alternate pavement type bidding, FHWA noted that "discount rates should be consistent with *OMB Circular A-94*" and that "The trend over the past 10 years indicates a [real] discount rate in the range of 2 to 4 percent is reasonable." The FHWA guidance also requires that any price adjustments used in comparing alternate pavement types during bid evaluation must be approved under Special Experimental Project #14, commonly referred to as SEP-14 (Stephanos Nov. 13, 2008).

The FHWA has produced a software package, RealCost, as a spreadsheet workbook that conducts LCCAs of pavement alternatives at the project level (*RealCost User Manual* May 2004). A number of state DOTs employ RealCost in analyzing pavement type-selection options.

State DOT Guidance

As state DOT examples, California and Colorado have issued guidance documents addressing LCCA use for pavement investment analyses.

- Caltrans has issued a policy statement directing the use of LCCA for most projects involving pavement work on the state highway system, regardless of funding source (exceptions are noted in the policy document). Corresponding changes have been made to the agency's design manual and project development manual (Land Mar. 7, 2007). Procedures for conducting pavement project analyses within Caltrans, using FHWA's RealCost software, are outlined in a Caltrans procedures manual (*Life-Cycle Cost Analysis Procedures Manual* Nov. 2007). Concurrently with this synthesis project, Caltrans is involved in NCHRP Synthesis 42-08 to investigate full-scale accelerated pavement testing (APT). The APT-related synthesis includes consideration of the economic costs and benefits of full-scale APT research, using the methods and criteria described in chapter two of this report (Steyn 2012).
- The Colorado DOT (CDOT) issues its guidance in the form of procedural reports. CDOT's history of written procedures for LCCA goes back to 1972. Although the original process remains essentially in place, it has been updated several times in the intervening years, with the latest update coming in 2009 (Harris 2009). CDOT also uses RealCost to conduct a probabilistic LCCA, primarily to compare alternatives in asphalt and concrete pavements.

Methods and Measures

In 2005–2006 a two-staged survey was conducted by Clemson University for the South Carolina DOT (SCDOT) on the use of LCCA for pavement type selection (Rangaraju et al. 2008). These findings are noteworthy because they provide an indication of agency practices in LCCA nationwide. Several of the findings below report data from the Stage 1 survey, which elicited 35 responses. Among the findings of this survey were the following, focusing on the economic dimension of the responses:

- Thirty-two of 35 agencies, or 91%, reported that they use LCCA as part of the decision process for selecting pavement type.
- Fifteen agencies (47%) reported using specialized software for LCCA; for example, RealCost and Darwin (an AASHTOWare product).
- Thirteen agencies (41%) include user costs in their analyses; 19 (59%) reported that they do not.
- The responses indicated a distribution of lengths of analysis period used in LCCA. Among 27 respondents, 4% used 20 to 29 years; 30% used 30 to 39 years; 40% used 40 to 49 years; and 26% used 50 to 59 years.
- There were also considerable ranges of values in the initial performance lives of flexible and rigid pavements. Flexible pavements elicited responses extending from 10 to 14 years to 30 to 34 years. Rigid pavement responses extended from 15 to 19 years to 35 to 40 years.

Recommended values by CDOT and Caltrans fall within the ranges of values cited earlier for each parameter, but exhibit the individual differences in practice between the agencies. For example, regarding lengths of the recommended analysis period, CDOT now recommends 40 years, whereas Caltrans recommends a range of values from 20 years to 55 years that depends on the respective alternatives being compared. The rationale of the two agencies in their selection of discount rate is also interesting to compare. Although both agencies arrive at a rate that conforms to FHWA guidance, they arrive at their recommendation in different ways.

- Caltrans considered the national data supporting a discount rate that was reported in *OMB Circular A-94,* and decided to compare those data with local experience. It considered returns to the state's Pooled Money Investment Account, a repository for surplus state cash, and found real returns for the past 20 and 30 years of 2.8% and 3.2%, respectively. Although the California data were backward-looking and the OMB data (*OMB Circular A-94,* Appendix C) are forward-looking, both suggested a real discount rate of 3%. The Caltrans team, which was considering changing the discount rate in its Cal-B/C benefit–cost program, was uncomfortable with a significant reduction from 5% (the former discount rate in Cal-B/C) to the proposed 3%, and opted instead for the compromise value of 4%. This rate is the Caltrans default value for all its BCAs. The Caltrans team recommended that future changes to the Cal-B/C discount rate be based on the *OMB Circular A-94* Appendix C data directly, which are readily available and updated annually (System Metrics Group, Inc. et al. Feb. 2009, pp. III-2–III-5).
- CDOT recently updated its approach to setting a discount rate. The approach is based on the 10-year moving average of the 30-year Real Treasury interest rates reported in *OMB Circular A-94,* Appendix C. This computation reflects, in CDOT's view, a stable estimate of interest rates corresponding to the most conservative, longest maturity investment strategy—a criterion appropriate to the assumption of a 40-year analysis period. When CDOT uses the 10-year moving average, the analysis covers a span of 20 years of averages, smoothing out the fluctuations. Even so, each year has a slight change in the computed interest rate. Because CDOT's intent is to use a stable, no changing yearly rate, an additional check is performed: to compare the current CDOT discount rate with the 10-year moving average plus or minus two standard deviations. Only if the interest rate changes more than two standard deviations from the current CDOT rate will a new discount rate be determined. This comparison is checked annually. For 2008 data, CDOT computed the 10-year moving average for 1999–2008 as 3.3%, which is the recommended discount rate (Harris 2009, pp. 5–8). For 2010, the discount rate remained at 3.3%.

Decision Support

FHWA and the state DOTs recognize that precise cost estimates and precise knowledge of life-cycle actions (e.g., the performance of pavement maintenance and repair) are not possible for the long analysis periods that are recommended. Many agencies therefore introduce a tolerance when comparing LCCA results, recognizing that small differences in cost may be the result of inherent uncertainties, and not to material differences between pavement alternatives. The Clemson–SCDOT nationwide survey indicated that, of 32 responses, 4 states base their pavement decision on the alternative with the lowest present value; eight selected the lowest-cost alternative if the cost difference exceeded 10%; and one respondent used a threshold value of 5%, another 15%, and yet another 20%. If the cost differences between alternatives are less than these threshold values, then one or a group of decision makers (e.g., a regional pavement designer or a pavement selection panel) makes the final decision. Other factors besides lowest life-cycle cost that are considered include constructability, material availability, design and environmental factors, continuity of pavement type, traffic control costs, availability of qualified constructors, and public/political issues (Rangaraju et al. 2008, p. 36).

- Caltrans uses a tolerance threshold of 5% between alternatives, or 2% if initial costs exceed $100 million (*Life-Cycle Cost Analysis Procedures Manual* Nov. 2007, p. 80).
- With its probabilistic approach, CDOT bases its decision on a comparison of the probabilistic results of the two alternatives when evaluated at a 75% confidence level (Harris 2009, p. 4).
- The use of probabilistic results in this way was also discussed by Rangaraju et al. as an effective way of managing risk. A threshold value of less than 100% recognizes that while using a 100% confidence level removes all risk from the evaluation, the result may not be economical. In addition to CDOT's threshold criterion, Maryland's 85% confidence limit was also cited (Rangaraju et al. 2008, p. 57).

Resources Required and Other Information

Resources

The resources required are implied by the previous discussion: knowledge of applicable guidelines, development of required data, and knowledge of the LCCA tools that are used. Responses to the Clemson–SCDOT survey indicated that, of 22 agencies that use LCCA for pavement type selection and that responded to the second-stage survey, 15 agencies (68%) were satisfied or had only minor concerns with their respective processes; 7 agencies (32%) had significant concerns about current LCCA application to pavement type selection. Among these issues were the following (Rangaraju et al. 2008, pp. 38–39, 81):

- Unreliable data quality.
- Lack of adequate training regarding LCCA programs such as RealCost, and inadequate understanding of the significance and implications of the input parameters to these programs.

- Difficulty in predicting materials costs given their rapid and significant fluctuations in price.
- Lack of sufficient historical performance data for newer pavement designs and materials (from which to estimate service life and rehabilitation/maintenance needs reliably and credibly for LCCA).
- Lack of "rational and predictable triggers" that signal the need for rehabilitation and maintenance.
- Lack of agreement with the asphalt and pavement construction industries on key parameters that are input to the LCCA.
- Concerns "from a political/market standpoint; that is, LCCA is not popular."

Issues raised by Canadian agencies in the same study reflected some similar concerns; for example, regarding data and methods, and need for training. Canadian respondents also cited lack of communication within agencies and between agency and political officials.

VALUE ENGINEERING

Introduction

The latest (2008) FHWA statistics on the use of VE by state DOTs show that among 382 studies completed nationwide, 139 (36%) were accounted for by 4 states ("FY 2008 Value. . ." 2009). Of these, the top two states, Florida and California, accounted for 82 studies, or 21%. This section presents two case examples, California and Florida, on a comparative basis to highlight similarities and differences. Florida refers to its effort as VE; California's process is discussed as Value Analysis, or VA. The two terms are treated synonymously in this section. When discussing the topic generally or when referring to Florida, VE will be used; when referring to California's approach specifically, Value Analysis or VA will be used.

VE is a systematic, structured process that reviews and analyzes a project typically during the concept development and design phases ("Value Engineering" 2010). Although VE may also apply during the construction phase, inviting suggestions by the contractor for an improved product, this case focuses on the project level and the design phase of the development cycle. The following discussion is limited to conventional construction projects and does not address design–build. Further information on VE practices among highway transportation agencies in the United States and Canada is provided in *NCHRP Synthesis 352,* including FHWA and OMB regulatory requirements for using VE (Wilson 2005).

Role of Economic Analysis in Highway Investment

FDOT defines VE in its guidance as follows:

> Value Engineering is the systematic application of recognized techniques by a multi-disciplined team which identifies the function of a product or service; establishes a worth for that function; generates alternatives through the use of creative thinking; and provides the needed functions to accomplish the original intent of the project, reliably and at the lowest life-cycle cost without sacrificing project requirements for safety, quality, operations, maintenance, and environment. *Source: Value Engineering Program,* May 15, 2008, p. 2.

The FHWA noted that the multi-disciplinary team appointed to conduct a VE analysis consists of persons who are not involved in the project and must include "at least one individual who is trained and knowledgeable in VE techniques and able to serve as the team's facilitator and coordinator" ("Order . . ." May 25, 2010). Project recommendations potentially provide the following benefits ("Value Engineering" 2010):

- Providing needed functions safely, reliably, efficiently, and at lowest overall cost;
- Improving the value and quality of the project; and
- Reducing the time to complete the project.

Caltrans identifies additional, more specific benefits in its guidance *Project Development Procedures Manual* (*PDPM Chapter 19,* p. 19–7; *Value Analysis Team Guide* 2003, p. 1.3):

- To foster a team approach to problem-solving and project development;
- To help build consensus among stakeholders;
- To identify and develop strategies that avoid or mitigate risks and associated costs; and
- To identify opportunities for Context Sensitive Solutions.

VE is an outgrowth of work in private industry during World War II focusing on managing value and innovation in a systematic way. The driving force was the wartime scarcity of critical materials, with impacts on U.S. defense manufacturers. The crucial insight was: If these materials were understood in terms of the functions they performed, then a focus on the function—function analysis—could, with creative thinking, lead to alternate materials, or different design concepts or manufacturing approaches, that might achieve the same function. This logic was later formalized in a "value analysis" process (*Value Standard . . .* June 2007).

VE in the public sector builds on these concepts of the analysis of value and function. The process has a long history of use by federal agencies, including its requirement in transportation beginning four decades ago. The FHWA maintains an active website on VE policy, practice, and accomplishment (www.fhwa.dot.gov/ve/). AASHTO provides guidance on VE (*Guidelines for Value Engineering* 2010), and state DOTs typically issue further guidance on VE within their own programs.

Table 14 identifies the scope of VE as required by FHWA for federal-aid highways, and by the two case example states

TABLE 14
SCOPE OF VALUE ENGINEERING PROGRAM

Scope or Scheduling Item	California DOT Value Analysis	Florida DOT Value Engineering
Federal-Aid Highway Projects; Federal-Aid Bridge Projects (i.e., those that use FAHP funding, whether or not on Federal-Aid system)	All projects ≥ $25 million Bridge projects ≥ $20 million Costs above encompass design, ROW, construction, project support U.S.DOT secretary may require VE (e.g., projects ≥ $500 million, or projects "of special interest") No waivers or exceptions	All projects ≥ $25 million Bridge projects ≥ $20 million Costs above encompass design, ROW, construction, project support U.S.DOT secretary may require VE (e.g., projects ≥ $500 million, or projects "of special interest") No waivers or exceptions
Non-Federal-Aid Projects	All projects ≥ $25 million Bridge projects ≥ $20 million Costs above encompass design, ROW, construction, project support U.S.DOT secretary may require VE (e.g., projects ≥ $500 million, or projects "of special interest") No waivers or exceptions	Projects ≥ $25 million Waiver may be requested case-by-case; director of Transportation Development must approve in writing for single project District flexibility to conduct VE on projects below $25 million threshold
Typical Candidates Among Projects Less Than $25 Million Threshold	VA "should be" performed on projects ≥ $15 million to enhance project value through use of VA and to avoid need to apply VA later in project development [*PDPM,* p. 19-7]. Caltrans districts are encouraged to voluntarily identify studies. Criteria might include; e.g., projects with: potential cost overruns, few identified alternatives, high maintenance costs, difficult safety/construction/ operational/ROW/maintenance/ environmental issues, complex geometry, major structures. Specific examples of candidate projects are not cited, but guidance documents support a broad scope of potential VA applications, including highway construction projects, highway product studies, and Caltrans process studies. VA can be used to build consensus among stakeholders	Projects substantially exceeding initial cost estimate Complex projects; capacity projects Corridor studies; interchanges Projects requested for VE by PM Projects with high ROW costs Projects, processes with unusual problems
Scheduling by Phase	Any stage of project development and construction, although VA is most effective in early stages of development process For DB: prior to RFP release.	One of following: Planning, Project Development & Environmental (PD&E), Initial Engineering Design For DB: prior to RFP release.

Sources: *PDPM*, Chapter 19; *Value Analysis Team Guide* 2003; *Value Engineering Program* 2008.
Regarding Caltrans requirements for non-federal-aid projects: Caltrans policy states that federal VE requirements for highway projects of $25 million or more (bridge projects of $20 million or more) apply regardless of funding source (Deputy Directive DD-92 July 2007). Therefore, non-federal-aid projects have the same VE requirements as federal-aid projects (based on 2007 SAFETEA-LU requirements).
Notes: ≥ = "equal to or greater than"; DB = design-build; FAHP = Federal-Aid Highway Program; *PDPM = Project Development Procedures Manual*; PM = project manager; RFP = Request for Proposals; ROW = right-of-way; VA = value analysis; VE = value engineering.

for nonfederal-aid projects. Table 15 describes team composition, process overview, and presentation of results as specified by California and Florida. At the heart of the economic evaluation is a BCA.

The scale of the VE analysis that will be needed depends on the scale of the project itself and other elements such as need for environmental review. Major projects will require a longer period for VE analysis, and more than one analysis may be called for at different stages through concept development, environmental review, and design.

Methods and Measures

The life-cycle costs and benefits supporting the VE proposals are applications of the net-present-value method applied to a

TABLE 15
VA/VE TEAM, TOOLS, AND RESULTS

Item	California DOT Value Analysis	Florida DOT Value Engineering
Typical VA/VE Team Composition	VA team selection is initiated by the DVAC and completed by the VA Team Leader in coordination with the DVAC, PM, and others attending a pre-study meeting. Key disciplines/functions needed on the project study should be represented. DVAC should contact function managers in advance of the study to identify and recruit candidate members. Roster lists VA team leaders and full-time study team members, project contacts, team resource advisors, study technical reviewers, and project decision makers. Expertise levels are identified for all except external stakeholders and decision makers. VA team members should be at either advanced or expert levels.	VE team selection coordinated between DVE and PM. Membership structured to include appropriate expertise to evaluate major aspects of project. Minimum: design, construction, and maintenance should be represented. Federal-Aid projects: personnel involved in design are information resources, but should not be team members. Districts determine whether membership comprises FDOT personnel, consultants, or combination.
Study Elements	Preparation Initiate study Organize study Prepare data VA Study Segment 1 Inform team Analyze functions Create ideas Evaluate ideas Segment 2 Develop alternatives, including LCC, benefits, and costs Critique alternatives Present alternatives Segment 3 Assess alternatives Resolve alternatives Present results: summarize performance, value, and cost improvements Report Publish results Close out VA study	1. Define original project objective 2. Identify design criteria for project 3. Verify all valid project constraints 4. Identify specifically the components and elements of high cost 5. Determine basic and secondary functions 6. Evaluate the alternatives by comparison 7. Consider life-cycle costs of alternatives 8. Develop detailed implementation plan 9. Determine which VE alternatives can be grouped together and which stand alone. Select the combination of solutions to recommend specifically.
Presentation of Results	Description of alternative Sketches (original design and alternative) Calculations Benefits Initial costs LCC	Description of alternatives Advantage/disadvantage comparison Evaluation matrix with weighted criteria Sketches: base design, proposed design Discussion, pros and cons Cost summary (see below) with supporting calculations
Form of Economic Results	Initial cost, annual cost, subsequent single costs (e.g., for repair, rehabilitation, and salvage value), and total LCC computed at specified discount rate Above costs computed for base design and alternative design. Yields result: Total Present Value Cost of each alternative, and difference between the two. Discount rate used in example reviewed: 4%	Initial cost, annual cost, and total LCC computed at specified discount rate Above costs reported for base design, proposed design (including implementation costs), and difference between base design and proposed design options. Yields result: either cost savings or the additional cost due to adopting the proposed design. Discount rate used in example reviewed: 7%

Sources: TVI International (1999); *Value Analysis Team Guide* (2003); *Value Engineering Program* (2008).
Notes: DVAC = District Value Analysis Coordinator; DVE = District Value Engineer; LCC = life-cycle costs; PM = project manager; VA = value analysis; VE = value engineering.

specified period (e.g., 20 years) at the discount rate indicated in Table 15. Examples of cost-benefit information used in and produced by a VA analysis are as follows (TVI International 1999).

Project Cost Information in Value Analysis (Caltrans example)

These cost items are computed by year for the base design and the proposed design alternative:

- Direct project costs: right-of-way, construction, and project support.
- Subsequent costs: maintenance and operations, rehabilitation.
- Mitigation costs: environmental mitigation actions for air quality, water quality, noise control, etc.
- Other costs: as specified by VA team.
- Total costs: totaled in constant dollars by year through the analysis period, with computation of present value.

Road User Cost Information in Value Analysis (Caltrans example)

These data items are computed by year for the base design and the proposed design alternative:

- Travel time: average annual traffic volume, total travel time, travel time reduction owing to the defined alternative, and travel time savings in constant dollars by year through the analysis period, with computation of present value.
- Vehicle operating cost (VOC): annual vehicle-miles of travel, total VOC, and VOC savings in constant dollars by year through the analysis period, with computation of present value.
- Accident cost: annual vehicle-miles of travel, annual number of accidents, accident cost savings as a result of the indicated reduction in number of accidents under the proposed design alternative; these cost savings are expressed in constant dollar by year through the analysis period, with computation of present value.

Tally of Cost and Benefit Results for VA (Caltrans Example)

- Net present value: computed by subtracting the present value of total project costs from the present value of total user savings comprising savings in travel-time costs, VOC, and accident costs.
- Internal rate of return: computed by testing at what discount rate the total (constant-dollar) benefits and the total (constant-dollar) costs are equal. If the computed IRR is greater than the discount rate used to conduct the analysis (i.e., 4% in Table 15), then the IRR result is equivalent to benefits exceeding costs and the net present value being positive; that is, the project alternative is economically justified.

As a further note on applications, Table 14 indicates that Caltrans' scope of VA analyses can include products and processes, in addition to transportation projects. Examples of these types of studies have been cited by FHWA in its VE website:

> In addition to studies conducted for the Federal-Aid Highway Program, Caltrans utilizes the VE techniques [Caltrans' VA process] to recently analyze improvements proposed for their 'Utilities Database' and 'Purpose and Need' processes. Caltrans also used VE to study a series of Safety Rest Area projects that had come in over estimated budgets to develop alternative ways to reduce construction cost while maintaining or improving project quality. *Source:* "FY 2007 Annual Federal-aid . . ." 2008.

Decision Support

An example of subsequent review and implementation of VA findings is provided by a Caltrans example for a new State Route, SR-138 ("Value Analysis Study . . ." 2009):

- VA team recommendations were submitted for review to identified agency managers and stakeholders; a 4-week review period was allotted. This particular study involved 11 VA alternatives.
- Following review, an implementation meeting was held to resolve the disposition of the 11 alternatives. An updated set of alternatives to be developed was agreed to by the VA team members.
- The VA team formally developed the agreed-on alternatives and suggestions that were accepted by the majority of stakeholders. (Note the entry in Table 14 that Caltrans guidance recognizes the use of VA to help build consensus among stakeholders.)
- These updating findings of the VA team were applied in the developmental phase of the project.

Resources Needed and Other Information

Resources

Overall team composition in FDOT is a district decision. Consultants often produce the VE reports, although there is no policy that dictates this practice. California's VA team composition is likewise tailored for each project, including representatives from the DOT, local stakeholders, consultants, and academics; the team may also use consultants to produce VA reports. Caltrans also explicitly considers the level of expertise for team members who are not stakeholders or agency decision makers. Key disciplines typically represented on a VE/VA team might include the following, as appropriate to the specific project: highway design, bridges or other structures, infrastructure construction, traffic operations (including access to modeling capability if user costs-benefits are to be estimated), environmental protection and mitigation, and maintenance and operations.

The tabulation of agency and road-user costs and benefits and the comparison of costs to benefits are accomplished using the Cal-B/C program (System Metrics Group, Inc. and Cambridge Systematics, Inc. 2004). Part of the information anticipated to be needed by the VA team is included in the project documentation for the existing design. This information includes project costs and data on current and projected traffic conditions for the existing design. Other data that may be needed can be generated by the VA team using traffic models (for impacts on travel time, VOC, and accident costs), engineering estimates (e.g., for initial, recurring, and annual costs of construction, maintenance, and operation of alternatives), and look-up tables that are part of Caltrans software (TVI International 1999, pp. 6.21–6.22).

Caltrans has performed a review of its VA program in terms of returns on effort, project dollar savings, and resources required to conduct VA studies in relation to benefits. Key findings were as follows for 286 VA efforts completed between 2002 and 2009 (Tusup and Hays 2009, updated by input from Tusup in 2010 for this report):

- The standard time devoted to a VA study is 6 days, ideally divided into two 3-day sessions. Five days is acceptable for smaller projects.
- Three days or less is not acceptable for a proper VA study. Four days would be the minimum for small, local projects that are off the National Highway System.
- Increasing the duration of the VA study can pay off in terms of both greater total project savings per VA study and the average savings realized for each day of the VA study effort. For example, although 3-day studies produced average construction savings of $2.81 million per VA study ($0.94 million per day of study), studies of 7 days or longer produced average savings per study of $18.45 million (roughly $2 million or more per day of VA effort).
- The VA team leader must be a Certified Value Specialist, with certification administered by SAVE International® (“Certification Program” 2010). The VA team leader preferably has experience in the Caltrans VA process. Team leaders must be independent of the project and of its design team.
- Qualified consultants may be used to conduct VA studies on federal-aid projects. Consultants with independent VA affiliates can perform VE on their own design, with independent team members not affiliated with the project.

Caltrans has identified typical problems using VA, but none of the listed items relates to the benefit–cost component of the analysis. Most of the issues relate to management and logistics; for example, failure to plan enough time and budget to do the job right; impact of accelerated design, which compresses the time schedule and begins to constrain the ability to make changes; and limitations on resources available (e.g., limits on Caltrans participation in local VA studies or the inability to schedule good meeting rooms for the time needed) (Tusup and Hays 2009).

ACCELERATION OF PROJECT DELIVERY

Introduction

The Minnesota DOT (Mn/DOT) applies economic analysis to a number of transportation issues that it faces and maintains a website providing guidance on benefit–cost methods (“Benefit–Cost Analysis for Transportation . . .” n.d.). Recently it applied economic concepts and methods to examine the benefits and costs of accelerating project delivery (HDR | HLB Decision Economics Inc. 2006). On-time, on-budget project delivery is becoming a major issue among national, state, and local transportation organizations across the nation. Streamlining project approvals and permits, together with accelerated project design and construction, are seen as critical to cost saving, improving mobility and safety, and maintaining economic competitiveness, while successfully preserving environmental quality and energy efficiency. Accelerating project schedules also entails risks, however, as in potentially greater mobilization costs and the possibility of missing and having to correct project details. Mn/DOT therefore sought to develop a methodological approach to analyzing the economic impacts of accelerating project delivery, accounting for the risks involved, and possible ways to mitigate these risks. In terms of the criteria for including this Mn/DOT work within this synthesis, the study is unique: It was believed to be a “first” in developing a “comprehensive methodological approach to estimating the economic impacts of transportation project delivery acceleration,” and to assessing the risk–reward tradeoffs of accelerated-delivery mechanisms such as design–build (HDR | HLB Decision Economics Inc. 2006, p. v). The case study used by Mn/DOT and its consultant to illustrate this approach was State Highway 52 in Rochester (ROC 52). In terms of the research framework established for this synthesis, this case example is at the individual highway project level, focusing on the project delivery stage.

Role of Economic Analysis in Highway Investment

Risk-Reward Framework

The rewards of accelerating highway project completion are described in the Mn/DOT study as follows (HDR | HLB Decision Economics Inc. 2006):

- The highway agency saves costs by reducing the effects of general inflation on project expenses as well as the impacts of possibly more rapid cost increases in items that are unique to highway construction; for example,

right-of-way acquisition in areas experiencing commercial and residential growth.
- Road users experience lower direct costs of traffic disruption resulting from construction in terms of travel-time costs, VOC, and costs of safety hazards.
- Communities experience less adverse impacts on the local economy in terms of reduced business volume and temporary reductions in housing values resulting from construction-related congestion, noise, and impaired accessibility.
- Project beneficiaries—road users, local citizens and businesses, the public at large—are able to realize sooner the economic benefits of the project because of the quicker completion of construction and the earlier opening of the highway to traffic. Within a discounted CBA, the discounted value of benefits is greater than would have been the case given a conventional construction time frame.
- Various ancillary benefits also accrue; for example, in program scheduling and management (project completions close existing commitments and enable schedulers to turn to new work); in reduced overhead and construction management costs; and in gains in productivity and efficiency necessitated by the tighter deadlines and the closer interaction between design and construction.

The HDR report to Mn/DOT acknowledges several risks in accelerated construction that are related to budget, project management/scheduling, engineering, and institutional arrangements (particularly those needed to prepare for actual construction; for example, right-of-way acquisition and utility work). The report discusses strategies to mitigate these risks, illustrated by the following examples (HDR|HLB Decision Economics Inc. 2006):

- Budget risks can be mitigated through clear delineation of funding sources and arrangements, a clear and realistic scope of work and project schedule, and a reliable cost accounting system with features that support effective cost tracking and management.
- Project management and scheduling risks can be mitigated by adopting and applying an effective project scheduling and tracking system, employing good communication with affected parties, instituting quality assurance steps such as constructability reviews and a system of incentives and penalties governing time and cost performance, and building in scheduling flexibility to adjust to project circumstances.
- Engineering risks can be mitigated through good management of the technical tasks and processes involved. Good practices include streamlining activities, maintaining good communications and coordination among stakeholders, organizing work tasks clearly within performing units, decentralizing personnel skills, strengthening organizational capabilities as through training, and shifting quality assurance responsibilities to the contractor to ensure its awareness of quality requirements.
- Institutional risks in utility relocation can be mitigated through mechanisms such as securing up-front contracts for major utility relocation and providing incentives for timely completion of utility relocation. Risk-mitigation strategies in right-of-way acquisition include offering various incentives to property owners such as signing bonuses, increased nominal values of parcels, and latitude in negotiating offers. Agencies can also provide employees training in environmental stewardship of sensitive land uses affecting the parcels being acquired.

Structure of the Economic Analysis

The analyses of these economic and financial effects of accelerated project delivery are summarized in Table 16. Costs, benefits, and other impacts of accelerated project delivery are structured in three categories: micro-economic impacts, which focus on transportation-related effects experienced by highway users; macro-economic impacts, which are experienced by the commercial and residential sectors of the local community; and agency-related impacts, which reflect the economic and the financial dimensions of changes in project costs owing to accelerated delivery.

- Micro-economic impacts comprise changes in the respective costs of travel time, VOC, crash or accident rates and severity, and environmental pollution resulting from vehicle emissions.
- Macro-economic impacts comprise changes in commercial business levels and residential housing values within the affected community.
- Agency impacts include effects on project-related costs and benefits in both an economic and financial dimension.

The table considers two distinct time periods:

- The period during project construction. The economic and financial effects identified in Table 16 are compared for a project with a more accelerated construction schedule versus that with a more conventional timetable.
- The period following completion of project construction. These project-driven transportation benefits, which reflect after-construction versus before-construction comparisons of highway performance and road user costs, would have been achieved by the project regardless of construction method. The key benefit of accelerated delivery by the agency is *to attain these benefits earlier than would otherwise have been possible* using more conventional construction approaches.

The ROC 52 example was intended as a first step by Mn/DOT to develop generalized economic analysis procedures that could be applied to accelerated-delivery options for other highways. In addition to the costs and impacts cited in Table 16, Mn/DOT and its consultant also ensured that

TABLE 16
STRUCTURE OF ENGINEERING ECONOMIC ANALYSIS DESCRIBING IMPACTS OF PROJECT ACCELERATION

Type of Impact	Period During Construction	Period After Completion of Project Construction
Micro-Economic	Reduced Period of Disruption to Highway User o Travel time cost o Vehicle operating cost o Crash or accident cost o Environmental emissions cost	Impacts of Congestion Relief o Travel time cost savings o Vehicle operating cost savings o Crash or accident cost savings o Environmental emissions cost savings
Macro-Economic	Impacts on Local Economy Due to: o Construction spending o Reduced period of disrupted access to local businesses o Reduced period of construction effect on housing values	Impacts on Local Economy Due to: o Incremental spending for operations and maintenance o Improved access to local businesses o Potentially changed housing values
Agency	Economic Effects o Reduced costs for time-dependent project items (e.g., construction management, project overhead, traffic management) Financial and Budget Effects o Reduced budget expenditures for time-dependent project items o Reduced impact of inflation on project costs	Economic Benefits to Public Provided through Agency's Decision on Accelerated Construction o Earlier attainment of project's benefits listed above

Source: Mn/DOT ROC 52 study (HDR|HLB Decision Economics Inc. (2006), Summary Table 1). Additional explanations and clarifications drawn from the report text, and a separate delineation of agency economic and financial effects, have been inserted by the author. This table presents impacts relevant to Mn/DOT and to ROC 52 highway users; other impacts (e.g., financial savings to city of Rochester associated with lower loan costs resulting from accelerated project completion) are not included.

the following characteristics of good practice would be met in estimating costs and benefits of accelerated construction for ROC 52:

- **Transparency:** Analytic methods and assumptions were reviewed by a multi-disciplinary panel of experts in economics, traffic engineering, planning, and local stakeholder interests. Reviews and discussions occurred at both a risk analysis workshop on the ROC 52 project and in subsequent meetings with Mn/DOT's Office of Investment Management. Suggestions were incorporated into the analysis described in subsequent sections.
- **Accuracy:** Quantitative data were obtained from authoritative public sources including the U.S. Census Bureau, the Congressional Budget Office, the Minnesota Department of Employment and Economic Development, the Minnesota State Demographic Center, and studies conducted or sponsored by FHWA.
- **Transferability:** The ROC 52 example provided a practical laboratory for developing and organizing the data, methods, and assumptions of the economic analysis into a computerized procedure (Microsoft® Office Excel workbook) that can be applied to other projects.
- **Risk Analysis:** Because the economic analysis embodies forecasts in its estimates, the value of each model parameter is expressed as a probability distribution. (These distributions were estimated at the risk analysis workshop mentioned in the first bulleted item.) Model outputs can also be obtained as probabilistic estimates, although for clarity they are often reduced to mean values or to a limited set of distributions. Confidence intervals and decumulative distributions can also be obtained.

Table 16 describes several components of the analysis conducted by Mn/DOT and its consultant, organized for use in this case example. In keeping with the objectives of this synthesis and the approaches that have been applied in other case examples, the focus of the remaining sections is specifically on transportation-related benefits and costs: that is, the agency-related economic costs and benefits and the micro-economic effects to highway users that are identified in Table 16.

Project Characteristics and Design–Construction Options

The ROC 52 project involved the design and reconstruction of approximately 11 miles of Trunk Highway 52, with the following work items:

- Widening from 4 to 6 lanes along part of the project length;

- Construction or reconstruction of interchanges and frontage roads;
- Construction of two new overpasses;
- Enhancements of ITS components; and
- Other improvements; for example, in road surfacing, lighting, signage, pavement markings, noise and retaining walls, traffic signals, and detention ponds.

Options to be considered in the economic analysis involved different construction-stage assumptions, including the use of design–build, to accelerate project completion. Mn/DOT and its consultant considered four options in establishing comparative estimates of time, cost, and impact:

- **Scenario 1, the Baseline:** Conventional design and construction wherein the design stage spans approximately 30 months (2.5 years) and the construction stage about 11 years, as estimated for the original project.
- **Scenario 2:** Conventional design stage with same duration as that in Scenario 1, but with a shorter period of construction of 5 years with funding restrictions removed.
- **Scenario 3:** Similar to Scenario 2, but with a further compressed construction duration of 3 years owing to some form of accelerated project delivery.
- **Scenario 4:** Application of a design–build approach to conduct design and construction in parallel, leading to a combined duration of design and construction totaling 3 years.

Comparisons among these scenarios were structured as follows:

- Scenario 2 compared with the Baseline Scenario 1;
- Scenario 3 compared with the Baseline Scenario 1; and
- Scenario 4 compared with the Baseline Scenario 1, and to Scenario 3.

Costs were also estimated for a "No-Work" or "No-Build" option, which assumed no improvements to the highway during the analysis period.

Methods and Measures

Micro-Economic Highway User Impacts

The beneficial impacts of project acceleration on highway users are measured in four categories of cost reduction: travel time, accidents or crashes, vehicle operation, and environmental emissions. The following sections discuss the factors included in calculations of each of these economic effects; mathematical formulas used in modeling computations are presented in the HDR report (HDR|HLB Decision Economics Inc. 2006, pp. 10–15).

Travel Time The total daily travel-time cost is computed at an aggregate level by vehicle type and peak versus off-peak period for each year of the analysis. In concept, the years may occur before construction (when congestion is affected by existing capacity prior to the project), during construction (when congestion is affected by work zone road occupancy and the duration of project work), and following construction (when congestion is presumably reduced owing to additional capacity provided by the project). Congestion effects are monetized in terms of total daily travel-time cost using a value-of-time calculation in each year that accounts for the following factors:

- The value of time associated with each type of vehicle in each year, in $/hour;
- A congestion premium expressed as the percent additional cost motorists are willing to pay to avoid congestion;
- AADT by period of day, vehicle type, and year (number of vehicles);
- The length of the project work zone in miles; and
- The average speed through the work zone by period of day and year, in miles per hour.

Accidents or Crashes Accident or crash costs are computed in terms of total daily accident-related costs by period of day, category of accident or crash, and year, accounting for these factors:

- AADT by period of day, vehicle type, and year (number of vehicles);
- The accident rate by period of day, category of accident, and year as estimated by FHWA for three categories of accidents: property-damage-only, injury, and fatal (accidents per some multiple of vehicle-miles);
- The monetized cost of a crash as estimated by AASHTO for each category of accident by year; and
- The length of the project work zone in miles.

Vehicle Operation VOC is the monetized value of owning, operating, and maintaining a vehicle as affected by road characteristics and conditions. The model used by HDR for Mn/DOT considered VOC in two steps:

- Constant-speed VOC for the following components: fuel consumption, oil consumption, vehicle maintenance and repair, tire wear, and roadway-related vehicle depreciation estimated for a constant-speed condition.
- Excess VOC, comprising adjusted consumptions of the VOC components for the actual traffic, pavement, and speed-flow conditions anticipated to be encountered within the time frame of the analysis.

The total daily VOC for each type of vehicle, period of day, and year of analysis was computed accounting for the following factors:

- AADT by type of vehicle (auto, truck, or bus), period of day (peak or off-peak), and year of cost estimation within the analysis period (number of vehicles);

- A constant-speed VOC consumption rate and an excess VOC consumption rate for each VOC component: fuel, oil, tires, vehicle maintenance and repair, and road-related vehicle depreciation, estimated for each vehicle type, year, and (for excess VOC consumption) period of day;
- Cost of each VOC component for each vehicle type and analysis year in terms of dollars per gallon of fuel, dollars per quart of oil, percentage of tire wear applied to total cost of each tire, percentage of average vehicle maintenance and repair cost, and percentage of vehicle-depreciable dollar value;
- Length of the project work zone in miles; and
- A pavement adjustment factor to reflect the influence of pavement condition on excess VOC.

Vehicle Emissions Vehicle emissions costs are the monetized values of air pollution released daily by vehicles. The daily cost of air pollution emissions is computed for each combination of the following: type of emission, vehicle type, period of the day, and analysis year, using the following factors:

- The rate of vehicle emission (in tons per numbers of vehicles) of each type of air pollution (hydrocarbons, carbon monoxide, and nitrogen oxides) by vehicle type, period of the day, and analysis year, obtained from FHWA emission-rate tables;
- AADT by vehicle type, period of the day, and analysis year (number of vehicles);
- Length of the project work zone in miles; and
- The emission cost per ton of each of the three types of emissions, respectively, in each analysis year.

Daily to Annual Conversion The four highway-user models described earlier yield results in cost per day. These cost results are converted to annual amounts using 365 days per year. Results for different project scenarios are also organized by whether the year corresponds to "during construction" or "post-construction" conditions.

Role of Forecasting The four models above all depend on forecasts of key variables:

- AADT is projected from baseline–year traffic volume using an average annual growth rate. Splits are applied to results in terms of peak versus off-peak periods of the day and vehicle type (autos, trucks, and buses).
- Volume-capacity ratios (v/c) are estimated for peak and off-peak periods based on AADT, assumed truck-equivalency factors, and proposed work-zone configurations and capacities.
- Average vehicle travel speeds for peak and off-peak periods are estimated using speed-flow relationships as a function of v/c and posted speed limits.

Benefits of Accelerated Construction Completion

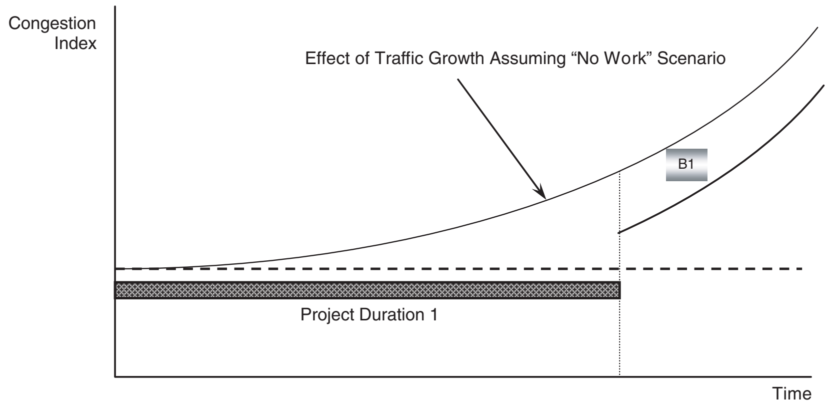
The benefits of accelerated project completion are illustrated in Figure 3, using the example of the congestion index (CI). (CI is a measure of urban traffic density on major metropolitan roadways. A value of CI greater than 1.0 indicates an undesirable level of congestion. This example is provided in the HDR report to suggest the general idea involved in calculating benefits of project acceleration. Other measures can be used for the four road-user models described earlier; however, the basic idea would be the same.) In the absence of a project (the "No Work" scenario), the congestion index is assumed to increase with growth in traffic demand (AADT). A project to increase road capacity would reduce the congestion index, providing a benefit to road users.

In the upper chart of Figure 3, project construction extends through Duration 1. At project completion the level of congestion is reduced, providing a benefit corresponding to the area B1 between the two CI curves. The lower chart in Figure 3 illustrates an accelerated project schedule that finishes project work within Duration 2, a shorter period of time. The resulting benefits are illustrated by areas B1 plus B2 between the two CI curves, providing an increased benefit.

There may also be benefits owing to the shorter project duration in the second chart, but these need to be confirmed using the several models discussed earlier. For example, it would be reasonable to assume that total work-zone congestion would be less with Project Duration 2, leading to additional travel-time savings in accelerated-completion scenarios. Incremental costs resulting from work-zone crashes are also expected to be lower with shorter construction duration, leading to greater safety benefits in terms of costs avoided. However, incremental VOC savings (especially in the fuel consumption component) may not be positive with shorter project duration, depending on the specific changes in speed and the number of stop-go cycles experienced by traffic through the work zone. The actual variations in road user costs that were computed across the four design–construction scenarios investigated are given later in this case.

Project Costs to Agency

Project costs for construction were estimated by HDR for each of the four scenarios defined earlier. Costs included direct project construction as well as several items that vary with project duration: temporary construction items, construction overhead, and construction management. Cost escalation (or inflation avoidance) was also included in the year-of-expenditure (Y.O.E.; that is, undiscounted) construction cost estimates; this component was carried over into the discounted CBA as well. (To the extent that this adjustment reflects differential inflation effects in construction costs, it would be consistent with guidance by FHWA and others cited in chapter two that recommends constant-dollar estimates in the economic analysis.) The total estimated project costs are given in Table 17.



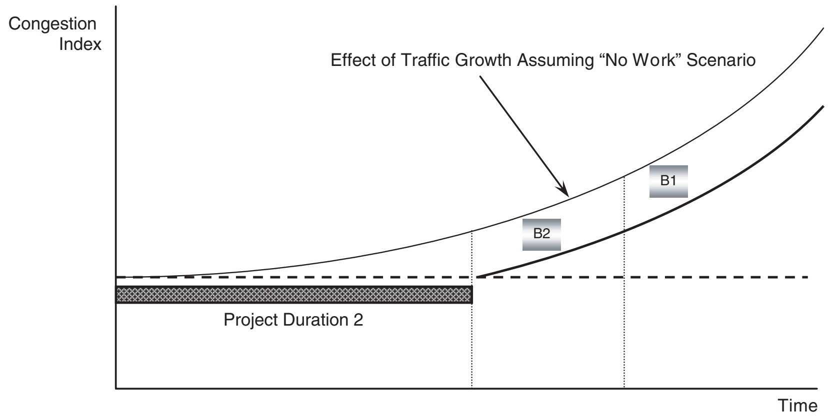


FIGURE 3 Illustration of highway user cost savings due to project acceleration. *Source:* HDR|HLB Decision Economics Inc. (2006), Figure 7, p. 11, with additional annotations by author.

Risk Analysis

The risk analysis conducted by Mn/DOT and its consultant was based on probabilistic input values of key variables. These ranges of values were then subjected to a Monte Carlo simulation, with results produced likewise as probabilistic distributions of costs and impacts.

- Input values were specified by three data points: an anticipated median value (i.e., with 50% probability of being exceeded); a lower-10% value (with a 90% probability of being exceeded); and an upper-10% value (with a 10% probability of being exceeded). These estimates were developed at a risk analysis workshop conducted at the Mn/DOT district office in Rochester before performing the economic analysis. The Monte Carlo procedure analyzed these data to infer a probability distribution for each input variable.
- The Monte Carlo simulation was performed employing the analytic models discussed earlier and the probabilistic

TABLE 17
ESTIMATED YEAR-OF-EXPENDITURE PROJECT COSTS BY SCENARIO

Scenario No.	Scenario	Cost, $ Millions
1 (Baseline)	Conventional design (2.5 years) and construction (11 years)	$371.4
2	Design (2.5 years) + reduced construction (5 years)	$280.2
3	Design (2.5 years) + accelerated construction (3 years)	$253.2
4	Design-build (3 years for design and construction)	$236.0

Source: HDR|HLB Decision Economics Inc. (2006), Summary Figure 4, p. xii, and Figures 20 and 22, pp. 37 and 38.

inputs. Results were produced as decumulative probability curves; that is, curves indicating the probability that a predicted result will be exceeded by the actual result. These curves enabled Mn/DOT and HDR personnel to identify the mean expected value, the value with 90% probability of being exceeded, and the value with 10% probability of being exceeded. Tables of results presented in a later section are based on mean-value results in each case.

To illustrate how the risk analysis was structured, Table 18 presents selected input variables in terms of probabilistic data developed at the Mn/DOT workshop. Where different time periods are cited (e.g., hourly vs. monthly vs. annual costs), the analysis translates these to commensurate project amounts. Costs in Table 18 are undiscounted.

Decision Support

Economic Analysis Results

The economic analysis of the ROC 52 construction options was conducted for a 20-year analysis period, 2003 through 2022. Project design was assumed to start in 2003 across all four scenarios. For Scenario 4 (the design–build option), construction was also assumed to start in 2003; for other scenarios, construction was scheduled to begin in 2005. Undiscounted or Y.O.E. costs were discounted to 2005 at a 4% discount rate. (Bear in mind that the ROC 52 project was serving as a case study for Mn/DOT and its consultant to develop this economic analysis for use in subsequent highway projects. Costs were thus discounted to the then "present year" of 2005, the year in which the economic analysis was developed, rather than, say, to 2002 or 2003, which would have been a more typical "decision point" for considering ROC 52 construction options in an actual project-development setting.)

Selected tables of results are presented here to illustrate different facets of the analysis results. The examples are for highway-user cost savings, relating to the models discussed earlier. Cost results are presented in Y.O.E. and total discounted amounts. Scenario comparisons are as discussed earlier: S2 versus S1 Baseline, S3 versus S1 Baseline, S4 versus S1 Baseline, and S4 versus S3, where "S" denotes Scenario.

- Table 19 shows predicted cost savings to highway users by component of user cost for each scenario, and the incremental cost savings for each scenario comparison. All costs in this table are in 20-year undiscounted Y.O.E. dollars.

TABLE 18
SELECTED EXAMPLES OF RISK-ANALYSIS INPUT DATA

Input Variable or Factor	Median	Lower 10%	Upper 10%
Project Costs (2002 $)			
Total direct project construction costs	$197,172,764	$197,172,764	$197,172,764
Monthly overhead costs (collocation office)	$97,222	$77,778	$116,667
Monthly construction management costs	$431,944	$345,556	$518,333
Warranty bond, cost per year	$52,350	$52,350	$52,350
Road User Value of Time (2005 $)			
Auto, $/hour	$10.46	$8.00	$14.10
Heavy commercial vehicle, $/hour	$19.39	$16.00	$24.00
Traffic Distribution			
Passenger cars and light trucks	93.5%	92.0%	95.0%
Heavy commercial vehicles	6.5%	8.0%	5.0%
Peak vs. Off-Peak Periods			
Length of the peak period, hours	5.0	4.0	6.0
Peak-hour traffic volume, % of daily volume	10.0%	8.0%	12.0%
Peak-period traffic volume, % of daily volume	65.0%	60.0%	70.0%

Source: HDR|HLB Decision Economics Inc. (2006), pp. 26–29.

TABLE 19
20-YEAR HIGHWAY USER COST SAVINGS BY COST CATEGORY ($ MILLIONS, UNDISCOUNTED)

Scenario Comparison	Travel Time	Accidents or Crashes	Vehicle Operation	Emissions	Total
Highway User Cost Savings Over No-Work (or No-Build) Option					
Scenario 1 (Baseline)	($27.7)	$38.9	$80.8	$16.8	$108.8
Scenario 2	$58.4	$62.8	$190.1	$1.9	$313.1
Scenario 3	$80.1	$69.5	$220.9	($2.2)	$368.2
Scenario 4	$87.5	$75.9	$242.7	($3.0)	$403.1
Incremental Highway User Cost Savings By Comparing Strategies					
Scenario 2 vs. Baseline	$86.1	$23.9	$109.2	($14.9)	$204.3
Scenario 3 vs. Baseline	$107.8	$30.6	$140.0	($19.0)	$259.4
Scenario 4 vs. Baseline	$115.2	$37.0	$161.9	($19.8)	$294.3
Scenario 4 vs. Scenario 3	$7.4	$6.4	$21.8	($0.8)	$34.9

Source: HDR|HLB Decision Economics Inc. (2006), Figure 18, p. 35.
Notes: Highway user *costs* are shown as *negative cost savings*. Round-off errors occur in some of the totals.

- Table 20 provides a summary of the micro-economic impacts expressed as highway-user cost savings in several ways simultaneously:
  - In 20-year undiscounted Y.O.E. dollars and in discounted 2005 dollars for the 20-year analysis period;
  - In two stages of the 20-year analysis: during construction (reflecting work zone and temporary road effects) and after construction (reflecting improvements derived from the project), and for the two stages combined;
  - In a comparison of total highway-user cost savings as compared with the No-Work (or No-Build) option; and
  - In comparisons among scenarios: S2 versus S1, S3 versus S1, S4 versus S1, and S4 versus S3.
- Table 21 illustrates the results of the risk analysis for the 20-year highway-user cost savings in undiscounted Y.O.E. dollars, organized by the four scenario comparisons.

Conclusions of the ROC 52 Analysis

Mn/DOT's consultant drew several conclusions from this economic analysis that are listed here. Although this case example has focused on micro-economic transportation impacts that are reflected in highway-user cost savings, the full Mn/DOT analysis considered other economic impacts as well; that is, changes in residential housing values, increases in local commercial activity, and reduced construction overhead costs. The HDR report includes findings that reflect these other aspects of the economic analysis. However, when *conservative* analytic assessments of transportation impacts were called for (specifically, to discuss the business case favoring use of design–build, as in Strategy 4 of the ROC 52 project), HDR focused solely on the highway-user cost savings, eliminating any possible double-counting among the other categories of economic impacts. This approach is consistent with the information presented in this case example. With this background, the overall conclusions as compiled in the HDR report are quoted as follows:

> By shortening the construction period and associated traffic disruption, project acceleration typically reduces highway user costs, and losses in housing values and retail sales in the immediate vicinity of the construction project. [This conclusion addresses the "During Construction" impacts.]
>
> By bringing the completion of highway projects sooner, project acceleration generates real economic value to highway users, avoiding congestion delays, highway accidents, and vehicle operating costs. The early completion of highway improvements also brings upturns in retail sales and home values sooner. [This conclusion addresses the "After Construction" impacts: both the generation of real benefits to road users, and the fact that benefits accrue to road users and the community earlier than they would with conventional construction.]
>
> Finally, through inflation avoidance and ancillary project cost savings, project acceleration is expected to reduce construction spending. *Source:* HDR|HLB Decision Economics Inc. (2006), pp. 46–47.

Resources Required and Other Information

Consultant Assistance with Methodology

Mn/DOT was assisted in this analysis by HDR|HLB Decision Economics Inc. (HDR), which developed the methodology, performed the economic analysis, and wrote the report cited in this case. Mn/DOT participated in this development through activities such as study oversight, provision of data, and conduct of the risk analysis workshop. Development of

TABLE 20
20-YEAR HIGHWAY USER COST SAVINGS DURING AND AFTER PROJECT CONSTRUCTION ($ MILLIONS)

All Estimates for 2003–2022	$ Millions, Undiscounted Y.O.E.			$ Millions, Discounted to 2005		
Scenario Comparison	During Project	After Project	Total	During Project	After Project	Total
Highway User Cost Savings Over No-Work (or No-Build) Option						
Scenario 1 (Baseline)	($123.7)	$232.5	$108.8	($90.8)	$98.0	$7.2
Scenario 2	($52.8)	$366.0	$313.1	($46.7)	$182.2	$135.4
Scenario 3	($33.0)	$401.2	$368.2	($31.3)	$210.7	$179.3
Scenario 4	($29.8)	$432.9	$403.1	($31.5)	$239.6	$208.1
Incremental Highway User Cost Savings By Comparing Strategies						
Scenario 2 vs. Baseline	$70.9	$133.4	$204.3	$44.1	$84.1	$128.2
Scenario 3 vs. Baseline	$90.7	$168.7	$259.4	$59.5	$112.6	$172.1
Scenario 4 vs. Baseline	$93.9	$200.4	$294.3	$59.3	$141.5	$200.9
Scenario 4 vs. Scenario 3	$3.2	$31.7	$34.9	($0.2)	$28.9	$28.7

Source: HDR|HLB Decision Economics Inc. (2006), Table 24, p. 44.
Notes: Y.O.E. = Year-of-Expenditure. Highway user costs (shown as *negative cost savings* in the "During Project" column) reflect traffic disruption due to construction. Highway user cost savings after the project reflect the resulting improvement in traffic flow. Round-off errors occur in some of the totals.

the analysis involved the following tasks (HDR|HLB Decision Economics Inc. 2006, p. 45):

- Review of the available literature related to the benefits of project acceleration, and identification of local, state, national, and international data sources for relevant economic indicators.
- Development of a model for analyzing project-acceleration benefits within a risk-analysis framework, addressing benefits in four areas: budget, financial, micro-economic impacts (the highway-user cost savings), and macro-economic impacts.
- Conduct of the risk-analysis workshop with Mn/DOT project stakeholders.

TABLE 21
RISK ANALYSIS RESULTS FOR 20-YEAR HIGHWAY USER COST SAVINGS ($ MILLIONS)

All Estimates for 2003–2022	$ Millions, Undiscounted Y.O.E.			$ Millions, Discounted to 2005		
Scenario Comparison	Mean Expected Value	90% Probability Exceeding	10% Probability Exceeding	Mean Expected Value	90% Probability Exceeding	10% Probability Exceeding
Scenario 2 vs. Baseline	$204.3	$168.7	$267.3	$128.2	$106.2	$167.1
Scenario 3 vs. Baseline	$259.4	$215.5	$335.2	$172.1	$143.6	$220.9
Scenario 4 vs. Baseline	$294.3	$244.5	$380.9	$200.9	$167.4	$259.2
Scenario 4 vs. Scenario 3	$34.9	$28.9	$45.9	$28.7	$23.7	$38.4

Source: HDR|HLB Decision Economics Inc. (2006), Table 25, p. 45.
Note: Y.O.E. = Year-of-Expenditure. "x% Probability Exceeding" means that actual savings have an x-percent probability of exceeding the predicted cost savings shown.

- Incorporation of expert panel comments within revisions to the analytic model.
- Conduct of the analysis, including the Monte Carlo simulations used in the risk analysis.
- Preparation of the report describing the analysis and results.

CASE CLOSURE

The several cases in this chapter have provided many examples of how engineering economic methods and data can be applied to investment decisions at a number of points in the life cycle of a highway facility. Each case, however, has focused on a particular application and the practices and viewpoints of a particular agency. The next chapter steps back from the set of cases to take a broader look at what economic methods mean to highway investment decisions overall. Chapter four addresses several important issues: the value of economic analyses, the role of economic analyses in strengthening agency decision making, the level of effort in using economic methods, factors favoring success, and useful resources available. There are also discussions of the relationship between economic analysis and performance measurement, the role of reporting and communication, and ongoing and emerging areas of application.

CHAPTER FOUR

IMPLEMENTATION

VALUE OF ENGINEERING ECONOMIC ANALYSIS

EEA has been successfully applied to highway investment decisions throughout the project and program life cycle, as summarized in Tables 3 through 6 and developed in the chapter three case examples. Viewed collectively, these examples demonstrate that when properly applied economic analyses yield several advantages:

1. **Determination of the merit of a project in economic terms.** Information on benefits and costs can be (and often is) supplemented by noneconomic and qualitative information to inform highway investment decisions that must respond to a range of policy goals and agency objectives.
2. **Analytic necessity.** It has long been understood that the costs, outcomes, benefits, and other impacts of transportation investments must be analyzed explicitly in a time dimension (refer to the nineteenth-century example mentioned in chapter one). Economic analyses enable managers to correctly compare and assess the dollars for an investment today versus the dollar amounts of costs and benefits to be incurred in the future. Straightforward engineering analyses, comparisons of initial costs of design and construction among project alternatives, and simplified economic methods (e.g., payback period) have their uses, but do not yield a full and fair accounting of future costs and benefits.
3. **Demonstration of tangible project benefits.** These benefits are typically estimated in terms of reductions in the cost of transportation to highway users, avoidance of costs to road users (e.g., costs of collisions or of congestion that are prevented), and avoided costs to the agency and ultimately to the public it serves (e.g., costs avoided through infrastructure preventive maintenance and reduction of environmental pollution). The maritime shipping analysis that is included in the Critical Facilities case example shows that these benefits extend to other transportation modes besides highways.
4. **Comprehensive estimation of project costs.** These estimates extend through the project life cycle, including costs of design, construction, maintenance, facility operation, rehabilitation, replacement, and removal or discontinuation if needed. Comprehensive estimates, done properly, disclose the full implications of the economic commitments to a project, establish a solid basis for parallel financial computations and forecasts, and help to avert unexpected and potentially onerous costs in the future.
5. **Development of an explicit linkage between highway performance and economic outcomes.** Costs and benefits, whether to the agency, road users, or the public at large, are influenced directly by the level of performance of the facility in all aspects—roadway and structure preservation, mobility, safety, environmental stewardship, energy conservation, and so forth. This linkage provides a strong motivation to embed economic thinking across the board, throughout an agency's business processes and in its internal and external communication of performance accountability.
6. **Facilitation of tradeoffs among disparate, competing transportation programs.** Preservation, mobility, safety, and other programs each have specific sets of performance measures. These measures are important for decision making (e.g., in diagnosing problems) and for accountability in monitoring progress toward targets. They can also be used in tradeoff analyses, where professional judgment is applied to assess, say, the need for additional mobility investment versus additional preservation investment. However, where different program outcomes can be computed as benefits, the commensurate performance measures in dollars can provide greater clarity when comparing alternatives in programming and resource allocation.
7. **Encouragement of innovative, creative solutions to problems.** Economic analyses encourage managers to see problems in new ways—the Safety Programming case example is an effective illustration. Given current budget pressures, WSDOT and other agencies have realized that a traditional, reactive approach to safety problems—responding to a limited number of high-accident locations with expensive road improvements—could not realistically address many other road safety needs and improve performance cost-effectively. More proactive, systematic, low-cost safety improvements are driven by the need to increase benefits while reducing costs; the case example describes the success of this strategy to date.

Of the seven items on this list, the first four are straightforward: the direct benefits of performing an EEA. They are typically the reasons that analysts add an economic dimension to an engineering comparison of alternatives. The fifth bullet, noting the linkage between facility technical performance and economic merit, has implications regarding transportation investment decisions and accountability:

- Among the set of technical performance measures used for a project, one or more could be able to be related analytically to costs (or costs avoided) that are incurred by the agency or highway users.
- Although technical performance measures (either outputs or outcomes) can provide insights into how and to what degree a project addresses a need, economic measures can help gauge the relative importance of these results as perceived by the agency or highway users.
- Economic measures of costs and benefits can assist in scaling and scoping a project appropriately, particularly when informed by (1) a forecast of available revenue for this program, and (2) cumulative program needs. (Refer also to the following discussion of the seventh point.)
- Technical performance results and economic measures of costs and benefits give different, but related, pictures of outcomes. One analysis can inform the other to gain a more complete understanding of the worth of a project.

The sixth point, regarding tradeoffs, recognizes that because dollars are additive regardless of the type of investment they represent, project-level costs and benefits can be aggregated to program-level totals for comparison and relative assessment. Although the tradeoff analysis described in the case example is a prototype and has not been implemented to date, it has been included as a useful example of a potential application of economic analysis.

The seventh point departs from an analytic perspective on economic analyses to consider its impact on organizational thinking and decision making. CBA and risk analysis impose a discipline on agency personnel not only to gather and properly apply good information about a candidate project, but also to subject candidate projects to closer examination. By scrutinizing costs, benefits, and their ratio, agency staff is prompted to consider implications and options:

- Does the benefit–cost ratio indicate that the project is worthwhile?
- Are costs reasonable in light of the benefits to be attained?
- Are benefits reasonable in light of the cost of the investment?
- Are costs realistically able to be funded in light of total program needs?
- Are benefits sufficient to yield a material improvement in overall highway performance?
- Will policy goals, agency objectives, and performance targets be met with the proposed mix of projects?
- Might other solutions yield greater benefits for cost or lower costs for a given benefit?
- Are there aspects of agency business and decision processes—data gathering and analysis, scoping of solutions to meet needs, evaluating competing solutions to recommend the best approach, using management systems, databases, and analytical tools effectively, reviewing research findings to gain new ideas, and so forth—that could be improved to make better decisions based on better information?

To address some of these questions, further interviews were conducted with the WSDOT State Pavement Engineer, who uses economic analysis to evaluate proposed pavement projects. Washington State was the subject of three case examples in recognition of the important role given economic methods and criteria by WSDOT and other units of Washington State government. This particular manager did not have a role in the earlier-described cases, however, so the discussion here represents a new perspective. The purpose of these additional interviews was to reinforce the findings earlier and understand more broadly how the use of EEAs has strengthened WSDOT's organizational capabilities for good decisions on highway investments.

STRENGTHENED AGENCY DECISION MAKING

Managers at WSDOT have found that conducting economic analyses, with the discipline imposed by that process, can yield additional benefits in improved decision making more generally. For example, in the course of defining and analyzing alternatives, managers may realize that additional alternatives exist that could yield even greater cost savings or benefits. An economic framework such as LCCA provides a generally understood, analytic basis for headquarters and field offices to discuss the engineering, economic, and other impacts of project alternatives. Two such examples are drawn from pavement type selection as practiced by WSDOT.

WSDOT conducts pavement type selection under the guidance of the department's Pavement Policy (*WSDOT Pavement Policy* June 2011). This policy document covers topics in new pavement design, pavement rehabilitation, technical design considerations, type-selection procedures, engineering reports, life-cycle cost worksheets, and typical inputs to the FHWA's RealCost program used by WSDOT for pavement-related LCCA. Although the *Pavement Policy* recognizes both the deterministic and the probabilistic analyses available through RealCost, it advocates the probabilistic capability to provide a risk analysis accompanying the economic estimates. If this is not possible, it recommends that at least a sensitivity analysis be performed using the deterministic analysis (*WSDOT Pavement Policy,* p. 48). If the difference in total life-cycle costs between two options exceeds 15%, the policy is to select the lower-cost option. If the difference in total life-cycle costs between two options is within a 15% margin, then other, project-specific factors are considered to judge the preferred alternative. These factors include, for example, various environmental impacts, nonuser impacts, safety impacts, pavement-type continuity within a corridor, and several other items listed in Appendix 6 of the *Pavement Policy.*

Day Versus Night Construction

WSDOT recently completed a pavement type selection for a state route widening project from 2 lanes to 4 lanes plus improved traffic channelization. Two pavement alternatives of equivalent design were considered: hot-mix asphalt (HMA) and portland cement concrete (PCC). In the original analysis, the PCC alternative was preferred. Although the total discounted life-cycle costs of the two alternatives were within 1% of each other, the road user costs with PCC were considerably lower than those for HMA, owing to fewer rehabilitation cycles during the 50-year analysis period. This and other project-specific factors weighed in favor of the PCC alternative.

In reviewing this result, however, the managers of the department's State Materials Laboratory realized that a nighttime construction option had not been investigated. A second LCCA was therefore performed based on night construction and rehabilitation for both pavement alternatives. Given the lower traffic volumes at night, road user costs during rehabilitation projects were considerably reduced. The updated LCCA result favored the HMA alternative by a margin exceeding 15%. The HMA alternative was therefore recommended and approved for this project ("SR 24/I-82 to Keys Road . . ." July 12, 2004).

The LCCA results for the HMA and PCC alternatives for both daytime and nighttime construction options are presented in Table 22. Both agency costs and road user costs have been reduced by WSDOT's decision to revisit the original pavement recommendation and expand on the options considered. Note that road user cost savings are significant. The overall discounted savings resulting from this exercise are almost $800,000.

Full-Depth Versus Non-Full-Depth Shoulders

On another state route widening project, a pavement type-selection analysis using LCCA was conducted to compare a PCC with an HMA alternative. The HMA alternative had lower life-cycle costs and was recommended for the project. However, in reviewing this result the managers of the department's State Materials Laboratory noted that the shoulders for both PCC and HMA alternatives were based on full-depth designs. Discussions took place at both headquarters and field levels on the pros and cons of full-depth shoulders for this particular highway. These discussions were based on engineering factors such as the performance of longitudinal construction joints, quality of base-course compaction, and impacts on construction staging and traffic. A key consideration was whether traffic might be routed onto the shoulder at some point; for example, during periods of construction and lane occupancy. Departmental review of these matters, headed by the State Materials Laboratory, indicated that many could be controlled through enforcement of construction specifications and were not related directly to the depth-of-shoulder question. It was believed to be unlikely that the shoulder would need to serve mainline traffic in the foreseeable future; projected growth was too low to warrant full-depth construction. Moreover, the cost of the full-depth shoulder, even for the preferred HMA alternative, was considerable—$1.2 million for the roughly 4-mile project ("SR 522—Snohomish River . . ." May 17, 2010).

Another LCCA was performed based on partial-depth shoulders for both the PCC and HMA alternatives. Nighttime construction was assumed throughout. The life-cycle cost results were structured in a sensitivity analysis that enabled comparison of alternatives based on the relative unit prices of PCC ($/cy) and HMA ($/ton). HMA was lower in total cost for almost all of the combinations of relative unit prices considered but with one exception, its cost advantage did not exceed the 15% margin needed for automatic selection. Noneconomic, project-specific factors were therefore considered, among them the greater surface continuity afforded by HMA, lower pavement-related noise attributable to HMA throughout the 50-year analysis period, and lower environmental and traffic impacts of PCC as a result of fewer rehabilitation cycles. Based on all of these inputs, WSDOT recommended and approved the HMA alternative, with an estimated 6.5% total discounted cost savings and a favorable review of its noneconomic advantages ("SR 522—Snohomish River . . ." May 17, 2010).

TABLE 22
LIFE-CYCLE COST RESULTS FOR PAVEMENT TYPE SELECTION COMPARING DAY AND NIGHT CONSTRUCTION

Pavement Alternative	Discounted Costs of PCC Alternative			Discounted Costs of HMA Alternative			Comparison HMA to PCC
Construction Option	Agency Cost ($$10^3$)	Road User Cost ($$10^3$)	Total Cost ($$10^3$)	Agency Cost ($$10^3$)	Road User Cost ($$10^3$)	Total Cost ($$10^3$)	Difference in Total Cost as % of HMA Total Cost
Day	$1,515.7	$299.1	$1,814.8	$985.1	$811.9	$1,797.0	–0.99%
Night	$1,509.6	$12.1	$1,521.7	$982.6	$35.3	$1,017.9	–49.5%

Source: "SR 24/I-82 to Keys Road…" (July 12, 2004).

Lessons from the Examples

WSDOT pavement managers regard their LCCA-based type-selection process as comprising "investment scenarios." Engineering considerations of options, coupled with the use of LCCA as a tool, lead to the best scenario from a technical and an economic perspective. By organizing costs and benefits (i.e., avoided costs) within a well-understood framework, WSDOT managers are then better able to focus on other factors that need to be considered in reaching a decision. These managers offered their observations on ways in which EEA helps to channel engineering, philosophical, and cultural inclinations toward constructive, unbiased outcomes. These observations have been combined with other lessons from the three WSDOT case examples described in chapter three to provide the following list of lessons learned overall:

- There is the tendency to try to include "nice-to-have" features in a project, particularly if "there's enough money in the budget," if work force issues are driving a high level of activity, or if there are regional political pressures for a more comprehensive project. If projects are not scoped correctly in the first place or conceived at the appropriate scale, designers may include more than what needs to be done. A solid economic analysis helps to realign thinking on the appropriate project scope and engineering approach.
- Perceptions of particular types of solutions; for example, a "preferred" paving material—may also skew judgments about crafting an effective solution. Again, economic analysis is helpful in evaluating the relative value of the performance of specific types of solutions.
- The SR 24 example, which revealed considerable savings accruing to nighttime construction once it was incorporated in the analysis, illustrates what can happen when a key option is excluded from the investment scenarios. As a matter of practice, WSDOT requires that LCCA include all potential scenarios. Adherence to this requirement led to the more cost-effective solution and the revision in the recommended pavement type.
- For correct project scoping and programming to occur, agency guidance must be clear, managers and staff must understand their roles, and communication must be effective. It is important that analytic tools for performing the economic analyses be easy to use and supported by good documentation. Data collection is to be timely, accurate, and complete, and provide information that is consistent with analyses and reports.
- In the face of budget limits, exercising diligence in seeking the most cost-effective solution is virtually a requirement. Certain state funding mechanisms in Washington constrain the projects, programs, and geographic areas that can receive dollars from that source. Cost savings in terms of these funds can be redirected to other eligible projects that reflect statewide priorities. Cost savings resulting from effective analysis of alternatives can be substantial, as noted in the previous examples.
- Washington State has a mature system of performance measurement and accountability reporting. *The Gray Notebook,* as the performance report is referred to, provides a dependable and well understood framework for communicating technical performance trends. Certain technical indicators tracked in the report are useful in estimating costs and benefits. WSDOT also has leveraged its database and GIS capabilities to provide effective graphical and analytic support for problem diagnosis, needs identification, analysis of alternatives, and decision making.
- WSDOT's communications internally and externally are effective not only in conveying information about current status and trends affecting the transportation system, but also in building credibility among stakeholders and the public that the department is investing wisely and serving as an effective steward of the transportation system. EEA allows agency managers to scrutinize project scoping and development to ensure the best possible solution. When called on, WSDOT reports to the legislature on its strategic management of programs. The most recent report was for pavement preservation and included the criterion of lowest life-cycle cost and actions to extend facility life and reduce costs. WSDOT also described key technological and economic trends; for example, 10-year plans for managing flexible (asphalt) and rigid (PCC) pavements, trends in pavement materials prices and strategic responses to them, and materials and methods such as recycling and permeable pavements (*WSDOT Strategies Regarding* . . . Sep. 2010). Annual reports on pavement condition, performance, and management are also included in *The Gray Notebook* (Feb. 18, 2011)

LEVEL OF EFFORT

The level of effort required to perform EEAs as part of an agency's business processes has not been extensively researched; this topic is recommended as a subject for further investigation in chapter five. From the case examples presented in chapter three, however, it is reasonable to infer the following:

- Caltrans' conduct of its Value Analysis (VA) studies directly quantifies the level of effort and the recommended participation of key staff. Based on this case example, a minimum 6-day commitment is standard, which may increase to 7 or more days if required by project scale, complexity, or other factors. Five days is acceptable for smaller projects; four days is the minimum for small, local projects not part of the National Highway System. Three or fewer days is not acceptable. Note also that existing data collection by Caltrans is already structured to support Value Analysis, and analytic models, including guidance for their use and staff training, have been in place for some time.

- Tables 3 through 6 represent a number of stages in the project/program life cycle, varying in their respective scope of activity and level of effort across agency units. The levels of effort to conduct economic analyses at each of these stages have not been widely researched (the Value Analysis studies by Caltrans are an exception). Comments by topic panel members who are actively engaged in conducting EEAs for state DOTs suggested that many analyses do not take much time to perform, but this experience has been gained with agencies that have integrated economic analyses within their business processes and developed a history of successful applications. Startup times and learning-curve effects may take longer for states that do not now perform economic analyses. It would require further research to quantify the times needed for analyses at each of the program areas and decision stages in Tables 3 through 6 for states with different levels of experience with economic analyses.
- For individual projects, unofficial guidance listed on the website of the TRB Transportation Economics Committee (ABE20) recommends flexibility in judging the appropriate level of effort to devote to economic analyses of transportation projects. Factors such as the cost of a project and the expected payoff could be weighed when assessing the level of effort to be assigned to an economic analysis. Specifically, the guidance recommends that the cost of a proposed level of effort should not exceed the cost-difference between two projects being analyzed. Rather, "effort should be concentrated on estimating and valuing the benefits and costs that are the largest and that differ the most between projects" ("Transportation Benefit–Cost Analysis" 2010, select link to "Level of Effort").
- Performance-based management is another field requiring organizational change and commitment to realize its benefits. (Discussion of the relationship between performance-based management and economic analysis is presented later in a separate section.) Guidance on how to view the level of effort needed to bring about this type of change is instructive:

> Public officials and managers sometimes hesitate to make the move to performance management because they fear that new costs will accompany the change. This fails to recognize the heavy costs often borne by governments that provide suboptimum services and make poor decisions without the benefits of data and analysis. The costs inherent in performance management are simply the costs of good management. *Source: A Performance Management Framework . . .* June 2010.

- In agencies such as Caltrans and WSDOT, where economic analyses are widely used and well understood, they are tightly integrated within multiple business processes. It may not be feasible (or meaningful) to isolate the level of effort attributable to economic analyses as opposed to the effort spent on "due-diligence" in reviewing agency products (plans, programs, engineering designs, etc.) and processes. For examples of this integration, refer to the cases for WSDOT and Caltrans in chapter three. These cases illustrate the following:
  - Tight integration implies economy of activities; for example, data collection and processing potentially simultaneously serve requirements of design engineering, traffic engineering, economic analyses, and performance monitoring. To arrive at a level of effort solely for economic analyses, it would be necessary to make arbitrary allocations of time and cost among these functions—allocations that might differ in other agencies.
  - Departments that use economic analysis effectively and efficiently assign high value to automating data collection, performing the economic analyses, and reporting results. The chapter three case examples illustrate that systems may be developed in-house (often with consulting or academic assistance), as with Caltrans' Cal-B/C, WSDOT's MP3 and Safety Management System, and the Mn/DOT spreadsheet workbook to analyze project acceleration options, or can be obtained from institutional or commercial sources (e.g., FHWA's RealCost). (Though not discussed in the case examples, AASHTOWare is another source of systems used by state DOTs.) Again, although the time spent in designing and developing these systems and providing support and training could be estimated, it would require an allocation scheme to distribute this effort among all the agency units and tasks that would use and benefit from system capabilities.
  - It would likely be difficult to derive estimates of "level of effort avoided" as the result of a good decision made at a timely stage using economic analysis. For example, regarding the two WSDOT instances discussed earlier—selection of a nighttime construction strategy and selection of partial-depth rather than full-depth shoulders—it is not clear what alternative project review mechanisms would have been necessary, or could have been applied, to arrive ultimately at the same conclusions but without the assistance of an economic analysis.
  - "Tight integration" can be complex and difficult to analyze, because it may exist both internally and externally with respect to the agency. Using WSDOT as an example, many agency business units are engaged in business processes that take advantage of economic analyses, both in headquarters and regional offices. Externally, WSDOT works closely with other state agencies, recognizing their involvement in tasks such as setting strategic statewide goals and data collection (refer to the Safety Programming case for examples). WSDOT also conducts extensive reporting of its accomplishments and performance measures to the legislature, governor's office, and other executive agencies, through *The Gray Notebook* and other mechanisms. These

reports include satisfaction of lowest life-cycle cost objectives, which are driven by state law.
– For agencies exhibiting (or seeking) this tight integration, it may be more fruitful for future research to focus on what factors make an integrated approach successful, rather than attempting to identify specific levels of effort associated with sole activity of economic analysis. Issues to be dealt with in future research might therefore include how integration of an agency's activities can be done skillfully to serve multiple uses efficiently, and what human, organizational, and technical factors within this integrated approach would enable economic analyses to promote greater team creativity and insight, leading to more cost-effective solutions.

SUCCESS FACTORS

Role of Champions

Studies of success factors have been conducted in two areas of transportation system management that make substantial use of BCA: transportation system safety and infrastructure asset management. One item that is associated with virtually all success stories of DOT initiatives is the role of a champion. A champion may be an individual or a group of individuals behind an effort; they may be within a DOT or external to it (e.g., a legislative committee or its full membership, the governor, a transportation commission or board, or an advocacy panel). Although the roles played by champions may vary, they tend to have the following characteristics in common (*State of Alaska* . . . Sep. 2007, pp. E-16 and E-17):

- They have not only a strong interest in the particular initiative they support, but are also in an institutional setting capable of exerting their influence in decision processes in which they are involved, as well as influencing how other groups address their initiative.
- In their positions of influence or leadership, they are able to get others to collaborate.
- They have a good grasp of the issues, are good communicators, and can articulate the reasons for collaboration.
- They have the tools to promote their initiative; for example, human, information, and dollar resources, and an organizational or institutional support structure.
- They are respected, trusted, and viewed as credible by others.

Organizational and Cultural Setting

With respect to the WSDOT Safety Programming case described in chapter three, a separate study has described institutional and cultural factors that have favored WSDOT's success in improving safety performance, reinforcing the efforts of the safety champions (Mercer Consulting Group LLC June 2007, pp. 21–22):

- The strong role played by the WTSC, with the support of the governor, in providing leadership and accountability in promoting a "culture of traffic safety" throughout the state. These groups would be regarded as safety champions external to WSDOT.
- Good working relationships among the WTSC, WSDOT, the state legislature, and other state and local entities. For example, the house and senate transportation committees strongly support the traffic safety initiative and other public policies through their actions on transportation funding. State agencies assist local communities in establishing local safety programs.
- Strong support by the public for effective safety policies, programs, and actions, which provides an incentive for agencies and the legislature to develop and implement innovative and effective solutions to safety needs.
- An aggressive goal (*Target Zero*) and WSDOT's history of establishing and maintaining effective partnerships and programs with other state and local groups to meet transportation challenges. This institutional framework, guided by a clear policy and performance target, has guided a successful, data-driven approach to addressing safety issues.
- Leadership and collaboration among all parties to deploy their resources behind key safety priorities and to communicate performance accomplishments through established mechanisms of state government accountability.

The importance of organizational culture in accepting EEA should not be underestimated. Material assembled for an executive asset management workshop indicated that changing the organizational culture was "the key challenge" to realigning organizational thinking to view asset management as a business focus (Ferragut and McNeil 2008, p. 34). This workshop pointed out that an important characteristic of successful asset management programs was the marshaling of agency-wide resources and capabilities toward this objective—exactly the characteristic observed in the successful, program-wide implementations of EEA in the chapter three case examples. This finding is further reinforced by a study of performance management within state and local governments, which stated that "to make real improvements, organizational culture must also be addressed" (*A Performance Management Framework* . . . June 2010, p. 2). (The relationship of EEA to performance management is discussed in a later section.)

Although economic analysis is a different subject from safety improvement, asset management, and performance management, there are important parallels that can be drawn in achieving success with initiatives in each of these areas. The development of an organizational and institutional culture favoring economic analyses at WSDOT is instructive, with a key role played by the state legislature as an external champion. (Refer also to the introduction to the Mobility Programming case example, which outlines the history of benefit–cost and lowest life-cycle cost criteria for capital programming at WSDOT, and the passage of enabling state legislation in RCW 47.05.) The following is based on the author's experience, with additional information provided in an FHWA case study ("Comprehensive Transportation Asset Management . . ." Apr. 2007).

- The investigation of a new capital programming approach, based on economic efficiency criteria, was initiated in a study sponsored by the legislative Joint Transportation Committee in the 1990s.
- Following completion of the study, state law was revised to require consideration of economic criteria in recommending highway projects and programs as part of the legislative budgeting process. This enabling legislation was RCW 47.05, discussed in the Mobility Programming case example in chapter three.
- This new capital programming approach was phased in over a period of a few years to develop the necessary analytic procedures and performance measures that support the economics-based calculations. Ongoing communications with legislative committees and members ensured that the new approach would be understandable and acceptable when used in program budget recommendations. Collaboration with other agencies, consultants, and academic experts was critical to successful development of specific methods and procedures within each transportation program, subprogram, and type of project. Champions supporting the use of engineering economics methods emerged within WSDOT as well as among external bodies such as the governor's office, the Office of Financial Management, and Washington Transportation Commission. Training of WSDOT staff familiarized them not only with the mechanics of how to apply the economic methods and criteria, but also with the change in thinking that economic analysis would bring about; that is, project costs had to be justified by project benefits.
- Since that time, WSDOT has continued to expand and refine the economics-based effort. The three WSDOT-related case examples (Mobility Planning, Mobility Programming, and Safety Programming) illustrate how the resulting organizational and institutional roles and capabilities, as well as the analytic methods and tools, characterize the successful application of economic methods.

Adapting to an Agency's Profile

Applications of economic methods in other agencies will rely on a common set of economic concepts and methods, such as LCCA and benefit–cost. However, they will likely differ in their specific objectives, motivations, needs, and requirements; their organizational and institutional roles and responsibilities; the public policy and political environment; and the particular analytic products and data that are used. Understanding these organizational, institutional, and cultural differences, and how economic analyses can be successfully applied in each case, is important to fostering more widespread use and acceptability of these methods. An approach that has been used in many studies is to develop agency profiles (e.g., FHWA's series of asset management case studies and AASHTO's primer on performance-based management). An implementation that parallels what could be called for in economic analysis appears in an asset management system study. The study develops agency profiles in tabular form to characterize successful system implementations in different organizational settings (Cambridge Systematics, Inc. Sep. 2010). A future research effort could use a similar approach to characterize profiles of agencies of different characteristics that have applied economic analysis broadly across a number of agency functions and stages of project/program development and implementation, and that routinely make use of this economic information in their business and decision processes. Details on this agency-profile research recommendation are provided in chapter five, drawing on prior work (Cambridge Systematics, Inc. Sep. 2010).

USEFUL RESOURCES

A number of resources are available with information on engineering economic methods and their uses. Basic information is provided on selected websites such as those maintained by Caltrans and Mn/DOT, and by the TRB Transportation Economics Committee (ABE20). These websites provide definitions and explanations of engineering economic methods (e.g., benefit–cost and net present value), as well as breakdowns of key elements of the analysis; for example, explanations of different components of transportation benefits (travel time, VOC, and so forth), and typical components of costs. Each agency may also include references to in-house applications, such as those for pavement type selection or VE, as well as descriptions of ITS that perform these analyses, examples of system reports, and case studies developed by the agency or by others. There may also be links to other relevant websites, and lists of applicable literature. For example, the TRB ABE20 Committee website includes links to state and provincial DOTs; federal, local, and international agencies; universities; and other relevant sites. Although WSDOT makes considerable use of economic analyses, its website is organized more along the lines of agency functions and business processes; for example, planning, capital programming, safety, and performance accountability. References to economic analyses are embedded within these descriptions or are accessible by means of links to documents describing WSDOT plans, programs, and studies.

FHWA maintains websites on economic methods and references documents such as those cited in chapter two. These documents specifically provide guidelines for using economic analyses for highway investments. They provide details on life-cycle cost techniques, uses of particular economic methods when analyzing highway investments, descriptions of ITS that employ economic analyses [e.g., FHWA's Highway Economic Requirements System (HERS), HERS-ST, and RealCost], guidance in matters such as selecting and using a discount rate, and suggestions for effectively using economic methods. NCHRP reports and economics papers in TRB's *Transportation Research Record* are also good current sources. All of these sources and the websites discussed previously have the advantages of being readily available and directly applicable to highway investments. Other useful references have been called out in chapters two and three. A bibliography is included following the reference list. There is a significant body of literature including textbooks related to EEA. However, care must be exercised where texts are oriented toward private-sector practices, because methods, nomenclature, and examples may differ from the definitions and guidance cited in this report.

The case examples have provided a number of instances of agencies' abilities to develop the data needed to drive successful economic analyses. Although the discussion of GAO findings in chapter two pointed to the potential difficulty in obtaining data that would be accepted by different audiences and researchers, the case examples nonetheless indicate that successful analyses based on credible data are achievable. This is true even for categories of data that were identified in chapter two as potentially problematic in their monetization; for example, travel-time savings, reductions in emissions, and reductions in serious accidents. A key strategy is to seek out as wide an array of potential sources of these data as possible. Data may be available from the resources of the agency itself: its own experience in managing projects and activities, its storehouse of historical data, and the analyses and databases associated with its management systems. If in-house sources are not available, data can be obtained from external sources in both the public and the private sectors.

- The Safety Programming case example illustrated WSDOT's use of IIHS data to better understand the types of safety problems on different classes of highways, as influenced by specific highway characteristics (e.g., number of lanes and curvature). The IIHS study was not only a source of data, but also an influence on WSDOT managers' thinking about how to approach the problem of collisions and what types of solutions might be technically and economically feasible.
- The Acceleration of Project Completion case illustrated Mn/DOT's use of a wide range of data sources encompassing federal, state, local, academic, consultant, and international studies. As one example, the monetization of vehicle emissions to account for the environmental pollution effects of different investment strategies during and after construction was based on unit cost data (dollars per ton of vehicle emissions) from the FHWA's HERS model.
- The U.S.DOT recommended values of travel-time savings and related guidance for various transportation modes and categories of transport users. These data are contained in guidance memos posted on the agency's website: http://ostpxweb.dot.gov ("Revised Departmental Guidance . . ." Feb. 11, 2003). Other potential federal and national sources of data and guidance were reviewed in chapter two.
- More comprehensive reviews of road costs are also available, including environmental and other social costs. For example, a comprehensive study of the social costs of motor vehicle use in the United States was conducted for the period 1990–1991 (Delucchi 1998). This study estimated the monetized value of a number of environmental impacts resulting from air, noise, and water pollution, as well as a wide range of social costs associated with accidents, parking, congestion, and vehicle use. Although the time frame of the study is limited to 1990 and 1991 data, its findings provide a framework for considering a broad range of costs that are not encountered in typical highway studies. They are also a point of departure for potential updates and adjustments to the data presented.

More comprehensive and sophisticated engagement of economic methods would benefit from the development of an agency profile (discussed earlier) for a peer DOT with a history of successful economics-based applications. For now, the case examples indicate that EEAs draw on a wide range of agency capabilities. These human, information, and organizational skills already exist generally within the typical DOT structure; the key is to bring these capabilities to bear in supporting the specific requirements of economic and risk management applications. An agency may already have a distinct organizational unit dedicated to economic analyses; however, this is not always the case, even among the state DOTs represented in the case examples. Additional desired capabilities suggested by the case examples encompass transportation planning, capital programming, relevant engineering disciplines (e.g., roadway design, project and program delivery, traffic engineering or operations, and maintenance), geographic services (to advise on or provide GIS and GPS capabilities), the transportation data unit (which may be attached to an engineering, materials, project, or program unit), information technology, the interagency coordination unit, and the legislative liaison office. It may also be desirable from time to time to consult with, or have the assistance of, the agency's research and library unit, the external reporting or communications unit, the strategic business planning or strategic assessment unit (which provides strategic direction and may oversee performance monitoring and management accountability), and the special studies unit (e.g., for major projects). Many of the case agencies consult academic or private-sector experts to advise on unusual or complex problems, or to develop unique or specialized analytic methods and organizational capabilities.

ECONOMIC ANALYSIS AND PERFORMANCE MANAGEMENT

Economic Versus Technical Performance Measures

A relationship between EEA and performance (or performance-based) management can be observed in the chapter three case examples, and is an issue recognized and discussed in the literature. The discussion is usually framed in terms of the measures produced by each practice; for example, benefit–cost ratio or net present value as economic measures of infrastructure investment alternatives, and technical condition and performance measures reflecting different engineering aspects of the infrastructure system that would result from investment alternatives. The key issues are what economic and technical performance measures represent in relation to one another, the relative value of the different types of information they convey, and how they work together to provide a more complete picture of the relative advantages and disadvantages of infrastructure investment options.

The Virginia Housing Development Authority has compared these two types of measures within its own discipline (*A Performance Management Framework* . . . June 2010, pp. 36–37, paraphrased and adapted to highway systems):

- EEA and resulting economic measures reflect the economic efficiency of an investment strategy, and the economic dimension of investment outcomes or impacts. They consider whether work procurement and performance were done efficiently regarding the type, amount, and quality of resources used (affecting the "cost" side of the calculation), and whether the work produced a value-added result (affecting the "benefit" side of the calculation). These analyses can be updated over time to determine whether other alternatives exist that can achieve objectives at lower cost (an interaction with the technical component).
- Engineering analyses and technical performance measures reflect the actual impacts or outcomes of an investment strategy. They indicate whether goals or objectives are being achieved by the results produced. They can also be used to assess whether goals, objectives, and targets are themselves suitable and relevant or need to be adjusted to account for revised trends, assumptions, and public policies; to identify factors that impede attainment of desired performance, and how updated solutions can improve system performance; to update these analyses over time to determine whether other alternatives exist that can achieve objectives at lower cost (an interaction with the economic component); and to determine whether the technical measures themselves are relevant, meaningful, and reliable.

"Value for Money" Concept

Economic methods and measures are unique in that they can express "value for money" of an investment, not simply its technical outcomes. An international scan of agency practices in Australia, Great Britain, New Zealand, and Sweden found that several agencies performed a BCA of every project. The benefit–cost ratio provided a common language for discussing project acceptability for selection and the value-added provided by a program, both internally and externally among other ministries, the legislature, and the public. It was also noted, however, that many *major projects* had other considerations driving investment decisions besides benefit–cost, including broader public priorities and political issues. Risk management techniques can play a role in assessing project suitability from an economic perspective. For example, sensitivity analyses or scenario testing has been used by these agencies to evaluate different types of bridge investments, to set appropriate speed limits, and to support safety improvements, all based on the concept of "value for money" (*Linking Transportation Performance* . . . Jan. 2010, pp. 7–8).

The scan report cited further applications of "value for money" that were combined with effective technical diagnosis of problems, reinforcing similar types of findings in the chapter three case examples (*Linking Transportation Performance* . . . Jan. 2010, pp. 11–12):

- A BCA conducted by the New Zealand agency found that increasing police enforcement at locations with recurring speeding problems would reduce collisions to yield a 28-to-1 benefit–cost ratio.
- The New South Wales Roads and Traffic Authority's diagnosis of safety problem areas showed that roadway departure crashes often occurred on horizontal curves where the radius was small enough to cause difficulty in handling the vehicle, but not small enough to prompt drivers to slow down sufficiently. By focusing limited safety funding on highway curves with these specific characteristics, they reduced roadway departure crashes cost-effectively through various countermeasures such as widened pavement and shoulder surfacing [refer to the international scan plus the following references: Levett (2007) and de Roos et al. (2009)]. Other examples of targeted, systematic solutions by Swedish and Australian agencies included the use of cable barriers and skid-resistant pavements at high-crash locations.

Toward Common Objectives and Purposes

The preceding examples illustrate that although economic and technical measures are distinct from each other, they serve a common objective and together can provide good insights into cost-effective solutions. The objective can be stated concisely as "better results for the public," where government bases its judgment of desirable results on its understanding of public needs and expectations. These needs and expectations extend to achieving cost savings and to improving performance against targets and attaining customer satisfaction (*A Performance Management Framework* . . . June 2010, pp. 2–6). This statement encompasses the principles of both performance management and EEA. Put into practice, it provides a strong contrast to more traditional ways of looking at public-sector projects and services:

> While bureaucratic processes focus on preventing bad things from happening, performance management [including analysis of economic performance] adds a focus that government actually

produces positive results. *Source: A Performance Management Framework* . . . June 2010, p. 4.

The theme of both technical- and economics-based performance in serving a unified highway program objective and purpose has been recognized in other references relevant to state DOT practice:

- An AASHTO CEO Leadership Forum on performance-based management cites one of the purposes of performance management as "assessing the status of a program [and] evaluating its cost- and [technical] performance-effectiveness." Also, "Successful implementation will continue to result in . . . [greater] results with constrained resources and fewer investments with low performance benefits" (Cambridge Systematics, Inc. May 2009, pp. 2-1, 4-2).
- The Leadership Forum document notes that some agencies set performance goals and targets based on a number of considerations: financial (considering realistic funding levels to achieve the goal), technical (goals should be achievable based on current and forecasted condition and performance), policy (goals must be consistent with existing policies and priorities, customer expectations, public outreach results, and executive and legislative input), and economic (minimizing life-cycle costs and maximizing benefits in relation to costs). A survey conducted for the Leadership Forum found that most respondents had developed performance goals for asset preservation and for safety. It is not uncommon for maintenance and preservation goals to be expressed directly in economic terms; for example, specifying cost-effective methods of accomplishment, with a goal of minimizing life-cycle costs, as illustrated several times in the referenced text (Cambridge Systematics, Inc. May 2009, pp. 2-7, 2-13, 2-14). Corresponding technical targets may be set in terms of engineering measures (e.g., levels of pavement roughness, serviceability, or surface condition index and values of bridge health index) that correspond to the minimum-life-cycle-cost principle.
- *NCHRP Report 551,* which considers performance measures and targets for transportation asset management, cites several examples where technical and performance measures are used together and interact with each other (Cambridge Systematics, Inc. et al. 2006). These cases include the development of long-term goals based on technical and economic factors (p. ix; refer also to the previous bulleted item); the strengthening of management systems to enable better executive decision support, CBAs, tradeoff analyses, and other higher-level analyses (pp. 43–44); inclusion of cost-effectiveness and benefit/cost measures within the set used to guide project selection and program-level tradeoffs and resource allocation (pp. 53–54); evaluation of investment tradeoffs based on life-cycle benefits and costs, as opposed to immediate impacts (p. 53); inclusion of road user costs and benefits within benefit–cost and cost-effectiveness measures where feasible and appropriate (note that road user impacts are functions of the road's technical condition and performance) (pp. 53, 55); and application of technical and economic measures to performance target-setting (p. 88).
- *NCHRP Report 551* illustrates the latter item on target setting by using congestion mitigation. Performance measures for congestion mitigation, including economic measures, should be meaningful at two levels: to the individual road user (e.g., commuter, traveler, passenger, shipper, and freight carrier) and at a more aggregate level indicating the overall magnitude of the problem given the composite traffic stream. At the individual level, appropriate measures might include travel time or delay per person, per trip, or per unit of freight carried. Measures at the aggregate level might include total hours of delay, percentage or statistical measures of reliability, or total dollars based on respective values of travel time across categories of road users or a monetized measure of travel reliability. These monetized, aggregate costs or costs avoided would be used in BCAs and provide a way of treating passenger travel and freight travel together. Monetized values of mobility depend on engineering performance of the highway link, corridor, or system: a function of its capacity and operational characteristics in relation to the traffic demand. To establish a base level for comparison to congested conditions, Caltrans and WSDOT have explored the use of "maximum productivity," a throughput concept reflecting an optimum combination of speed and traffic volume, as a target. This optimum tends to occur at speeds near 50 mph on a freeway, higher than target speeds of approximately 35 mph that have been used as targets in congestion analyses in the past. This approach shifts the nature of the mobility target from the notion of "what might be achievable through additional mobility investment" to "what is the operating efficiency of the highway now and after the investment" (Cambridge Systematics, Inc. et al. 2006, p. 88).
- Although economic measures convey information on the relative merits of investment alternatives, technical measures also play important roles in analyzing strategies. *NCHRP Report 551* observes that the Ministry of Transportation of Ontario (MTO), which uses financial measures of asset value relative to their replacement cost as high-level system preservation measures, continues to rely on technical condition information for more detailed performance analyses. Asset management systems for pavements and bridges are able to apply detailed deterioration models to predict future asset condition in terms of these technical parameters. Such predictions enable a wider and more precise set of analyses than would be possible using the simpler forecasting models for asset value alone. Furthermore, although financial asset value encourages continued investment in preservation to maintain that value above

a defined baseline, it does not yield information on the cost-effectiveness of investment options that do so. Economic analyses are still needed for this purpose (Cambridge Systematics, Inc. et al. 2006, p. 65).

Ex-Post Analyses

International Scan

Some overseas agencies visited on the international scan for performance management evaluate the impacts of major projects after they are completed (that is, in an ex-post or post-construction analysis). In an economic context, this analysis indicates to what degree the benefits estimated in the project's before-construction BCA were actually realized by the completed, operational facility. More generally, the analysis can consider what went right and what went wrong on a project assessment, with lessons for future evaluations of highway investments. The scan team included post-construction evaluations of project economic analyses in its "lessons learned" recommendations for the U.S. transportation community (*Linking Transportation Performance* . . . Jan. 2010, pp. 7, 13).

European EVA-TREN Project

A considerable amount of work on ex-post evaluations and their role in strengthening economic assessments of projects has been accomplished by the European EVA-TREN project team. EVA-TREN stands for EVAluation of Investment for TRansport and ENergy Networks in Europe. Its team represents a consortium of European university research institutes.

> EVA-TREN is a research project supported by the European Commission . . . The main objectives of the project are:
>
> - reviewing the ex-ante assessment approaches for large infrastructure projects;
> - selecting the best practices; [and]
> - improving the assessment methodologies for the ex-ante evaluation through [an] ex-post evaluation.
>
> [*The*] *EVA-TREN project aims at improving the ex-ante appraisal practices for the assessment of large Energy and Transport Infrastructure projects through the ex-post analysis of several case studies. Furthermore, the project will also develop a document containing evaluation guidelines on the topic. Source:* EVA-TREN website: www.eva-tren.eu/project.htm.

Most of the following material is drawn from papers and proceedings that were prepared in conjunction with the 1st Experts' Workshop for EVA-TREN held in Lausanne, Switzerland, on November 7, 2006. The findings cover not only the importance of ex-post analysis in strengthening the information basis for highway investment decisions, but also comparable practices (or lack thereof) in Canada, the United States, and Japan. Although much of the writing reflects the European context in terms of highway programs and funding, the following points have general applicability for the economic analysis methods followed in the United States and other countries. To maintain consistency with the original sources, the terms ex-ante and ex-post will be used frequently, as well as CBA for cost–benefit analysis. In U.S. practice, these terms may be used synonymously with pre-construction, post-construction, and benefit–cost analysis (BCA), respectively, or comparable nomenclature. The reviewed literature on the subject will be distilled to its essential points; readers may consult original sources for more detail. The following specific points are from a working paper supporting the EVA-TREN project (Florio and Sartori Jan. 2010):

- Ex-ante CBA assessments of projects vary considerably in their quality and assumptions. Common shortcomings include incomplete or inconsistent information and errors in methods; for example, different analysis periods (time horizons) for similar projects, different assumptions in the treatment of externalities, and inaccurate estimates of future traffic demand (particularly overestimation of demand) and of project costs (differences in actual-to-estimated cost on a set of EVA-TREN project studies ranged from −17% to +116%). This initial weakness in the ex-ante estimates in turn confounds the ability of ex-post analyses to yield useful information. The problem of inaccurate estimates echoes the discussion of forecasting bias in the methodological issues discussed in chapter two.
- Systematic ex-post evaluations are needed to correct problems in the ex-ante estimates and to determine whether divergences are the result of methodological errors, incorrect assumptions, or changes in the external project environment. Properly discerning the causes of incorrect forecasts is the only way to determine the steps needed for improvement. Building incentives to conduct ex-post analyses into an agency's business processes and personnel roles and responsibilities is an important aspect of ensuring that these analyses contribute to improved decision making.
- The objectives of an ex-post analysis according to the EVA-TREN project are:
  - Increased transparency regarding the impacts of a transportation investment in meeting its economic, financial, environmental, and social goals.
  - A measure of the utility of a project as well as the quality of the ex-ante estimates of its merits.
  - Identification of ways to improve future ex-ante estimates by providing feedback on methods, assumptions, and data.
  - Collection of data on projects to be used for future reference.
  - An incentive for better, more accurate ex-ante estimates in the future by describing publicly the real, demonstrated achievements of completed projects.
- EVA-TREN has identified the steps contributing to a correct ex-post assessment as follows:
  - Establish what has to be evaluated. This is a matter of understanding the primary objectives and targets

of a project, its bounds, and relevant questions that need answering.
- Measure the outcomes of a project. This involves first considering the no-build option: what would have happened if the project had not been built? This step establishes a benchmark against which project outcomes can be compared. Second, define the outputs and performance measures to be used, and obtain the data to quantify these results. Practical considerations are important to controlling the costs of acquiring this information.
- Compare the ex-post evaluation results with the expected project outputs from the ex-ante stage. Results to be compared (recall that these projects can be in transportation or energy) can include project costs, revenues, demand, and impacts in the several dimensions discussed earlier (economic, financial, etc.). It is important to identify not only the differences ex-post to ex-ante, but also, to the degree possible, what has caused these discrepancies.
- Classify the results and their likely causes of success or failure. The EVA-TREN re-examinations of its case study projects have underscored the importance of understanding "Why?" as well as "What?" happened on a project. It is important to learn whether the causes of inaccuracies or errors in the ex-ante projections of project impacts were the result of internal factors (e.g., errors in assessment methods, data, and assumptions; incorrect assessments of risk or uncertainty), other project-related factors (e.g., ex-ante forecasts and estimates were valid, but project management failed to deliver on expectations), external factors (e.g., natural disasters, unexpectedly adverse weather, and other unlucky events), or external project environment updates (e.g., changes in policy or in public expectations).

Further information is provided in additional working papers prepared for the EVA-TREN experts' workshop (Chevroulet Jan. 2008 and Feb. 2008), the workshop proceedings (*EVA-TREN: Improved Decision-Aid Methods* . . . 2008a), and the annex to the proceedings (*EVA-TREN: Improved Decision-Aid Methods* . . . 2008b). Key findings relevant to this synthesis include the following:

- Methods of appraisal among the European Union (EU) countries "differ considerably in scope, sophistication, methodology, and parameter values"; research results on these methods "are not fully transferred between countries"; and transnational projects within the EU remain difficult to complete efficiently. Given one examined fund as an example, the result is that cost overruns affect the majority of projects, with the average overrun 15% to 20% above budget (EVA-TREN proceedings, 2008a, p. 4). The different practices and levels of sophistication noted among EU nations recalls a similar diversity in the level of attainment among U.S. state DOTs described in chapter two.
- The workshop proceedings observe that the United States has "no official requirements or guidelines for ex-post evaluation of transportation projects" (EVA-TREN proceedings, 2008a, p. 12).
- Problems with existing ex-ante and ex-post evaluations and associated CBAs are as follows (EVA-TREN proceedings, 2008a, Table 7.1, p. 15):
  - The CBA methodology is often unclear or weak because of the different treatment of basic problem parameters and economic impacts.
  - The CBA methodology does not exist or is structured only in financial, not economic, terms.
  - Project documentation is weak or lacking in important data (e.g., on project output).
  - It is difficult to establish the ex-post economic rate of return owing to lack of a clear project description or a comparison between the build and no-build cases.
  - The ex-post economic rate of return is lower than the ex-ante estimate as a result of changes in project parameters (e.g., the investment amount, project output, or timing of events) or in methods and data (e.g., shadow prices or inclusion of externalities).

These issues recall analogous concerns expressed by FHWA in reviewing the economic analyses accompanying the TIGER grant applications (chapter two). In raising these issues, the EVA-TREN team seeks to assist EU agencies in being more aware of observed shortcomings and problems with economic analyses, and to improve both their ex-ante and ex-post estimates according to the recommendations described earlier. The EC *Guide* (discussed in chapter two) mentions ex-post analyses and an ex-post perspective, but does not go into the methodology in detail. The EVA-TREN documents listed previously provide more comprehensive information and guidance.

Other Examples

Other examples of ex-post analyses have been reported as follows:

- A review of benefit–cost ratios with regard to the benefits of public investment in Australia's road infrastructure, developed for the Australian Automobile Association (The Allen Consulting Group 2003).
- A review of the causes of project delays and estimates of the cost of these delays, accompanied by re-estimates of the project benefit–cost ratio to compare ex-ante (or appraisal) with ex-post B/C values, prepared as a research study in public policy in Japan (Morichi et al. 2005).
- The re-examination of the centerline rumble strip solution described at the end of the Safety Programming case example in chapter three, an example of ex-post analysis applied by a state DOT.

Although not strictly an ex-post analysis, the methodology developed in the Accelerated Project Delivery case example illustrated the use of data from a completed project to build a method for use on future projects. As more general guidance, it is recommended that agency staff validate the data used in performance management analyses, which would apply to economic analyses as well (*A Performance Management Framework* . . . June 2010, p. 35).

Further Lessons

The literature has provided additional lessons with respect to performance management, of which economic analyses are an important part. These are summarized here.

- WSDOT has distilled its experience with performance management to several concise guidelines (Cambridge Systematics, Inc. May 2009, p. 4-1):
  - "Keep perspective. Performance measurement is one of several decision-making tools."
  - "Timing is everything. Don't delay until you have the perfect data, framework, or IT system."
  - "Lead, don't follow. Tell your story before someone else tells it for you."
  - "Don't tolerate silos. Strive for a 'One DOT' mentality."
- The international scan regarding performance management reported that Queensland addresses financial risk in future maintenance commitments for existing infrastructure by estimating unfunded liabilities resulting from deferring or under-investing in maintenance. This calculation is supported by data from asset inventories and use of asset management systems and techniques. The calculated liabilities are formatted within a balance sheet-type statement. The scan also reported that Sweden, the United Kingdom, and New Zealand used variations of this approach to consolidate infrastructure financial needs within a unified statement of future public-sector liability for facility preservation (*Linking Transportation Performance* . . . Jan. 2010). (Although a sufficient level of funding is a financial, not an economic, issue, ensuring that financial liabilities are met is important to maintaining the integrity of the LCCA on which the project was originally justified. For example, if it is believed that legitimate maintenance needs cannot be met on future projects, other project options; for example, involving a premium or low-maintenance design and higher construction quality—might be more realistic and preferred in terms of technical and economic performance.)
- Commenting in an interview on the relationship of economic analysis to performance measurement, a state DOT manager noted that her agency looks to performance-based planning as a way of directing project solutions to identified performance needs or problems. The usefulness of economic analysis is sometimes diminished by relatively narrow choices set up for evaluation—that is, alternatives between specific projects of one type as opposed to different types of projects or solutions. (For example, the move toward systematic, low-cost solutions would define a different approach to safety needs from more traditional, larger-scale, reactive projects. Also, the two WSDOT pavement examples earlier in this chapter illustrated in their initial results the pitfalls of too narrow a consideration of project options.) Further, economic analysis can be misapplied to justify a project for which a decision to build has already been reached. The ongoing movement at the national level (e.g., in the TIGER grant process) to demonstrate more transparently what the public is getting for its transportation investments may improve the application of BCA.

COMMUNICATION AND REPORTING

NCHRP Report 551 emphasizes the importance of communicating and reporting performance results. Although the content and detail of reports to technical managers, political leaders, other stakeholders, and the general public may differ, in general the communication of information on transportation system performance, including its economic performance and the value of program investments, is important across all these segments of the audience. Effective reporting of program accomplishments and communication of the value received from transportation investments reinforces the credibility of the program, contributes to a better understanding of benefits received by the public, establishes accountability for program results, and strengthens the public's support of transportation policy (Cambridge Systematics, Inc. et al. 2006, p. 42). These two messages—the importance of communicating results effectively and understanding diverse needs for information among different groups within the audience—is repeated in guidance on performance management. Good information "can provide the vehicle for understanding results and trigger discussion and debate on how to improve the results" (*A Performance Management Framework* . . . Jun. 2010, p. 40). The case examples in chapter three for the most part are built around communication of information in a technical context, as would be the case in transmitting information to agency managers and professional staff.

A variant on the largely tabular reporting methods used in the cases is a graphical approach employed by the San Francisco Bay Area Metropolitan Transportation Commission (MTC) in appraising its competitive slate of candidate investments. This approach entails plotting the benefit–cost ratio against the number of defined transportation goals satisfied by each proposed program investment. A schematic of this graphic is shown in Figure 4 (*Performance Assessment Report* . . . Dec. 2008).

The bubble shapes represent the average result for projects of a particular type of investment; for example, freeway widening, transit-oriented development, high-occupancy toll

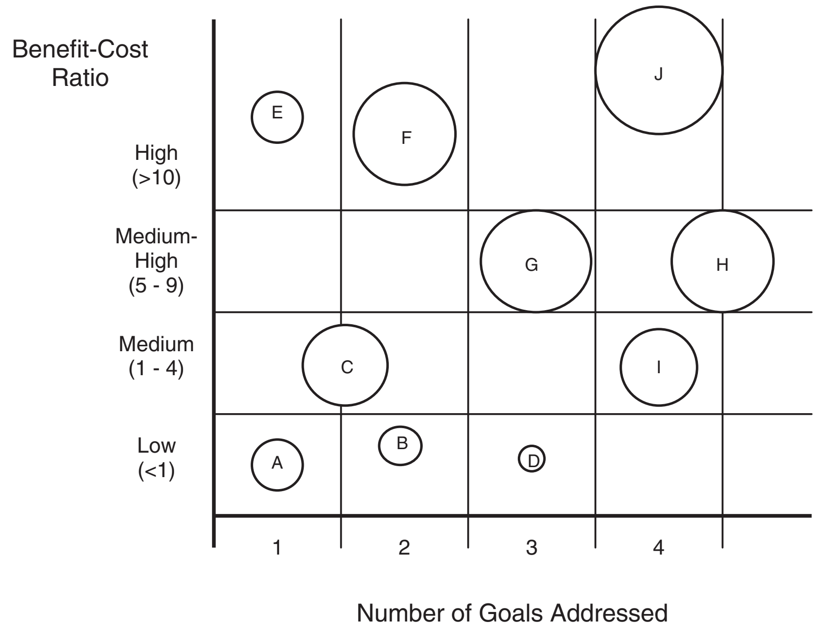


FIGURE 4 Schematic: MTC performance assessment graphic (adapted from *Performance Assessment Report . . .* Dec. 2008).

lanes, and emissions reductions. For simplicity, these classifications of projects are referred to here as "categories." As a schematic, Figure 4 illustrates ten categories of project investment, A through J. The MTC includes street and highway, transit, nonmotorized, and climate protection/emissions reduction categories in its candidate project investments. The relative size of each bubble represents the annualized benefit computed for the plan target year: in this case, 2035. The bubbles are plotted according to their computed benefit–cost ratio and the number of defined transportation goals that they are judged to serve. In several cases the programs are shown satisfying goals partially: this allows the MTC to distinguish among "strong support of," "support of," or "be neutral toward" a goal. Goals are expressed qualitatively; for example, support of system maintenance; congestion relief; emissions reduction; focused growth; access to transportation for youth, elderly, and disabled persons; and nonmotorized safety.

Figure 4 enables MTC professionals to assess the results and conduct discussions of tradeoffs in selecting project categories for investment. The strongest categories are in the upper right, displaying both high benefit–cost ratios and satisfaction of multiple goals. The lowest performers are in the lower left. Organizing the results this way helps ensure that high-end performing categories of projects are included in planned investments; for example, H and J. Low-end performers (e.g., A, B, or C) would be included only if there are other compelling reasons to do so; for example, they represent a local high-priority category or they address a special need (e.g., lifeline transportation). The MTC may also choose to weight some goals more highly than others to see how results are affected. Also note that Figure 4 treats all modes listed earlier in the same way, with the same economic, policy, and technical criteria judging projects of different categories. In this manner, the figure serves as a way to see how the economic performance of project categories can be combined with other technical and socioeconomic criteria to understand the relative benefits of each category and thereby to inform tradeoffs and decisions on transportation investments.

ONGOING AND EMERGING AREAS OF ANALYSIS

Work to extend the applicability of engineering economic methods is proceeding on several fronts as indicated by the synthesis survey results, interviews with practitioners, current areas of research, and the literature review. Following are examples illustrating the range of recent activities and trends in thinking.

- Agencies are strengthening their capabilities to do EEAs. Survey responses and findings from the literature review provide the following examples:
  - One agency is developing economic-based methods for programming and resource allocation for "other asset" (i.e., nonpavement, nonbridge) categories. EIAs are done for selected major projects.
  - In a second agency, a PMS is nearly operational that will take budgets and apply them to the pavement conditions to develop network scenarios.
  - A third department reports that it is in the early stages of developing economic analysis methods for

the following program categories: ITS, other operations (one of three urban mobility categories, the others being urban capacity and ITS), and economic impacts.
  - A fourth DOT is developing a set of economic analysis guidelines that will appear on the agency website. The department is also looking at techniques based on road user costs to establish budgets for mitigating construction-related impacts on traffic. Agency staff uses ITS Deployment Analysis System software to prepare economic analyses for potential ITS projects, with the objective of prioritizing ITS investments. With the relative scarcity of O&M funding, the economic analysis helps establish the business case for these ITS investments that sustain ongoing O&M commitments. Finally, this state has a long-standing statutory requirement to prepare BCAs for major projects, which are new or relocated highways comprising more than 5 lane-miles.
  - An analytic tool has been developed for a state DOT to provide consistent methods and data for the economic analysis of project costs and benefits. The tool is based on the AASHTO *Red Book,* with a customized version of the Redbook Wizard to allow a different procedure for input data on traffic volumes, travel times, and highway capacity (Findley et al. 2007).
- Engineering economic methods have been applied, or are under research for application, to assessing a wider set of highway features, particularly some of the newer, highway operations-related devices; for example, ITS technology, including ITS-controlled (automated) applications of anti-icing chemicals to prevent wintertime accidents (Stowe 2001); electronic toll collection systems (Li et al. 1999); intersection safety hardware (Madanu et al. Feb. 2010); and IntelliDrive deployment for wireless networking of data among road vehicles, road infrastructure, and passengers' personal communications devices (NCHRP Project 03-101, announced in FY 2011).
- Engineering economic methods may also be applied to topics involving the value of information, including the value of research. Examples include the application of benefit–cost methods to the use of Road Weather Information Systems to inform decisions on anti-icing applications and other weather-affected maintenance activities (Boselly 2001; Boon and Cluett 2002); to freeway management systems ("Freeway Management Systems" n.d.); and to the use of information from full-scale APT facilities (Steyn 2012).
- FHWA and GAO observations on the competition for the first installment of the TIGER grant program were described in chapter two. Among the findings of those reviews were: (1) transportation agencies, including state DOTs, will conduct economic analyses if they are required to and this requirement is perceived to be in their broader self-interest; (2) the quality of the project economic appraisals varied, with the higher-quality submissions illustrating that economic analyses are indeed practical to conduct given data and methods typically available to transportation agencies, and the lower-quality submissions exhibiting various errors and incomplete data and options; and (3) changes in program administration could be considered to provide a fairer, better informed, and more transparent process for evaluations in future iterations of the grant program. In the context of this chapter, the TIGER grant program has been regarded as a potential model for future funding programs based on competitive project merit rather than a formulaic nationwide distribution of funds. The GAO is particularly interested in a federal surface transportation program that is more performance-oriented and that uses a merit-based competitive approach to fund transportation projects of national or regional significance. A recent GAO study included several recommendations for future discretionary grant programs such as the TIGER grant program (*Surface Transportation: Competitive Grant Programs* . . . Mar. 2011):
  - If Congress deliberates such a competitive grant program it may wish to consider ways to balance the competing goals of merit-based competition and funding distribution based on geographic equity, perhaps with mechanisms to limit the geographic influence.
  - To provide greater transparency in U.S.DOT decisions on grants, the secretary of transportation might document the circumstances of key decisions, particularly the reasons for accepting or rejecting grant applications and the decisions in which lower-rated applications are selected for award over higher-rated applications.
  - The secretary of transportation, in consultation with the U.S. Congress, might develop and implement a strategy for disclosing information on grant-award decisions.
- The Puget Sound Regional Council (PSRC) employs a BCA that includes reductions in travel-time unreliability as one of its benefit components. Unreliable travel time reflects the risk that passenger and freight road users might experience excessively long travel times under onerous conditions. The PSRC computation translates this risk into a "certainty equivalent": essentially a willingness-to-pay concept to reduce this risk. This procedure is implemented in PSRC's B-C analysis (*Analysis and Forecasting* . . . Oct. 2009). Other transportation agencies, including the state DOTs reviewed in this synthesis, typically include travel-time reductions in their assessment of highway-investment benefits, but not reductions in the variability of travel time. Travel-time reliability (or unreliability) is a concern to all road users, but has a specifically economic dimension to freight traffic. There is a demand for the capability to include travel-time reliability in benefit–cost calculations and exchanges of ideas on this topic

are ongoing, as demonstrated by an international forum on travel-time reliability and CBA held in 2009 ("Value of Travel Time Reliability . . ." Oct. 2009). Further research is needed to develop and implement this idea more widely, including both the analytic treatment of the variation in travel time and the estimation of the time-dependent value of different categories of freight.

- Road user costs are often modeled as a function of traffic flow, speed, and congestion (refer to several case examples in chapter three), but the relationship between user costs and pavement surface condition has not been updated for U.S. highways in more than 20 years. NCHRP Project 1-45, Models for Estimating the Effects of Pavement Condition on Vehicle Operating Costs, is nearing completion and will provide new models of fuel consumption, tire wear, and vehicle repair and maintenance costs as a function of pavement roughness.

CHAPTER FIVE

CONCLUSIONS

STUDY OBJECTIVES AND CASE DEVELOPMENT

Objectives and Scope

The objective of this project was to study current practices by U.S. state transportation agencies in performing engineering economic analyses (EEAs) to evaluate highway investment decisions. The scope of these investigations included analysis techniques, processes, and resources currently being used, knowledge of which might be helpful to other agencies considering the use of economic methods. According to the Scope of Work for this synthesis, past research had indicated that certain transportation agencies are proficient in integrating economic analyses of their investment options into their asset management strategy using a variety of tools and processes. Other agencies were found to lack the resources, guidance, and understanding to perform such evaluations for other than a few, limited applications. The purpose of this study was to build on these earlier assessments and develop specific findings on how proficient agencies—those state DOTs and other transportation agencies that are conversant with economic methods—apply EEAs. A series of case examples would be used to demonstrate methods, data, assumptions, results, and applications to highway investment decisions that typified unique, comprehensive, or innovative uses of EEA.

The Scope of Work made the case examples central to the conduct and the findings of the study. It was agreed with the topic panel that the synthesis would present only a brief overview of engineering economic methodology and data, referring readers to other references for additional information on these subjects. The value-added products of this study would be the descriptions of how successful state departments of transportation (DOTs) and other transportation agencies go about the steps of EEA: articulating the highway system need or problem to be investigated; defining alternative solutions to be assessed; quantifying the parameters of the analyses; setting economic and engineering criteria for decisions; introducing other, noneconomic or nonquantitative factors affecting the outcome; completing the analysis; and interpreting results.

Case Identification and Development

Based on the literature review, the most widely used applications of economic methods in the United States today focus on project-level engineering decisions related to pavement and bridge preservation, spot-location safety improvements, evaluation of major projects, and urban highway analyses [e.g., mobility improvements and the growing use of Intelligent Transportation System (ITS) devices]. Of key interest for investigation in this synthesis were unique applications (e.g., problems not widely addressed, as in evaluation of different methods of project delivery); broad, comprehensive applications (e.g., applying EEAs across a range of decisions in the project life cycle and at different levels of the highway system); and innovative applications (e.g., applying utility theory to represent benefits that are otherwise not easily quantified). The other criterion in selecting case studies was the ability and willingness of the host agency to describe the case and provide needed data.

The study employed several mechanisms to identify candidates for case examples. These included a literature review, presentations before two committees at the TRB Annual Meeting, interviews with topic panel members and other industry experts in the field, and a screening survey. The screening survey questionnaire was sent to state DOT representatives on AASHTO's Standing Committee on Highways, with copies to each state DOT's Research Advisory Committee member, and a corresponding questionnaire to each state's FHWA division office. Responses were received from 17 state DOTs and 8 FHWA division offices. For two states responses were received from both the DOT and the FHWA division office; these were combined to produce a single response for each state, resulting in 23 unique state responses. Of these 23 responses, 20 states reported using EEAs, whereas 3 described themselves as not using such analyses. The 20 affirmatively responding states were considered as candidates for case examples; the 3 states that responded negatively provided reasons why their state highway agency did not use economic analysis on a routine basis. The survey results were used solely as a screening device to identify candidates for case examples and to obtain background information on usage patterns. The background information was not used as a statistically significant indication of nationwide practice. The survey results were consistent, however, with previous research and with findings of other surveys having higher response rates.

Case Examples

The findings of all of the sources of information converged on a particular set of case examples, which are presented in chapter three. An extension of all of these cases to discuss implementation issues and considerations is presented in chapter four. The categories of case examples in this synthesis include the following:

- **Critical Interstate Facilities,** illustrating economics-based planning analyses by the Port Authority of New York and New Jersey of its interstate bridges and tunnels, with an accompanying economic analysis by the U.S. Army Corps of Engineers of changes in future maritime shipping as the result of the Panama Canal capacity expansion.
- **Mobility Planning,** illustrating planning-level tools now being put in place by the Washington State DOT (WSDOT) as part of their technical and economic analysis of their highway improvement program.
- **Mobility Programming,** illustrating WSDOT's benefit–cost analysis (BCA) of highway improvements for project prioritization and building the highway improvement capital program. The case explains screening criteria applied to project candidates, multi-objective evaluation criteria (economic benefit–cost, environmental impact, stakeholder response, and interaction of project design with factors such as land use and use of alternative modes including nonmotorized transportation), analytic procedures, and application of results to prioritization, program building, and budget recommendation.
- **Safety Programming,** illustrating WSDOT's benefit–cost approach to systematic, low-cost safety improvements, with explanations of geographic information system-based capabilities for problem diagnosis, prioritization, and selection of proposed solutions. The case explains WSDOT's *Target Zero* strategic highway safety plan, its safety project priority levels, methods of analyzing safety needs and solutions, and organizational and institutional relationships that support a coordinated and effective statewide safety program.
- **Bridge Programming and Permitting,** illustrating a unique approach by the California DOT (Caltrans) to analyzing bridge project priorities regarding critical, risk-related needs that are not addressed in Caltrans' bridge management system. Caltrans applies utility theory to gauge the benefits of reduced risk of scour, reduced risk of seismic damage, and bridge railing safety. Results are applied to bridge project prioritization using a multistep inspection, evaluation, and peer review process, conducted in the context of environmental permitting requirements for bridges that are near coastal zones, in environmentally sensitive areas, or are of historic importance.
- **Economics-Based Tradeoffs,** illustrating the development of a prototype, economics-based tradeoff analysis by the New York State DOT. The benefits measure used is excess road user costs (or costs avoided).
- **Pavement Type Selection,** illustrating the economic evaluation of competing pavement alternatives by Caltrans and the Colorado DOT. Explanations of each state's approach to determining a discount rate are provided in this case.
- **Value Engineering (VE),** illustrating methods of conducting VE by the Florida DOT and Caltrans, two agencies that account for the largest number of the state DOT VE studies in the United States. The case is noteworthy in its description of the well-structured VE approach used by Caltrans, including data on the duration of these reviews and quantification of resulting project cost savings.
- **Accelerated Project Delivery,** illustrating the development of a new methodology by the Minnesota DOT to analyze options for speeding completion of project construction (or design and construction, as in design–build). This method applies a BCA of project phases during construction and after construction, which has been built using data, models, and risk assessments developed during a recently completed highway expansion project.

Each case addresses a number of aspects suggested by the Scope of Work; for example, an Introduction describing the case and highlighting ways in which it is unique, comprehensive, or innovative; the Role of Economic Analysis in Highway Investment, laying the groundwork for the case description and the approach to be used in its analysis; Methods and Measures, developing the methodological aspects, key variables, and measures to characterize results; Decision Support, describing how the economic analysis results are applied to decision making, what other factors (including noneconomic and nonquantifiable considerations) are incorporated in the decision process, and the resulting decision if available; and Resources Needed and Other Information, including any unique capabilities or resources required for the analysis.

FINDINGS

Case Example Results

The case examples apply conventional methods of EEA, but each is tailored to the particular problem at hand, and several employ software (including spreadsheet workbooks) developed by an agency or its consultants. Project costs include typical costs of work on transportation facilities, encompassing preliminary engineering and project preparation; design; construction; and maintenance and operation as appropriate. Project benefits typically include savings in travel time, in vehicle operating costs, and in costs of collisions, but selected cases (such as the Bridge Programming and Permitting example) use specialized benefits measures: in the bridge case, a measure of bridge health encompassing vulnerability to catastrophic damage, expressed as a utility function. The quantification of other input variables is covered as applicable to each case. Certain cases also describe the agency's method of determining the value of the discount rate that is used in the economic analysis.

Similar explanations are given in each case example for the measures of results. Where estimates of life-cycle benefits and costs are both available, a BCA is applied with the economic results metric expressed as a net present value, benefit–cost ratio, or in some cases an internal rate of return. If a monetized benefit stream is not available, a cost-effectiveness analysis is applied, as for the Bridge Programming and Permitting example in which benefits are expressed through changes in the bridge health utility function. Other measures of benefits used in the case examples are road user costs avoided (or excess road user costs) and collision frequency and severity for safety analyses, which can also be used in a cost-effectiveness calculation. Several cases also illustrate the application of risk analyses, using sensitivity and scenario analyses or probabilistic input values.

Characteristics of Proficient Agencies

Viewed individually, the case examples show how engineering knowledge and a need to understand the impacts of particular decisions can be organized within a practical economic framework. Viewed collectively, however, the case examples begin to reveal characteristics that are held in common among agencies successfully applying engineering economic practices:

- Establishment of solid, understandable, and up-to-date agency guidance on how, when, where, and why to apply economic techniques, with the support and participation of executive leadership.
- Development and use of analytic tools, accompanied by the definition, collection, and use of quality data, needed to support economic analyses.
- Incorporation of these analytic tools within day-to-day business processes, with an agency expectation of their effective use backed by executive leadership.
- Effective integration of engineering as well as economic logic within analytic procedures.
- Use of cost-effective software such as spreadsheet workbooks and databases in which to develop, use, and communicate EEAs.
- A willingness to experiment and innovate when existing data and analytic capabilities do not fit a unique situation that requires a decision.
- The capability and willingness to undertake reasonable, realistic estimates where hard data are not available.
- Maintaining a healthy perspective on EEAs, viewing results as information—not an automated decision—that becomes part of an overall understanding of a problem.
- Providing staff training in economic methods and tools, and encouraging personnel to apply these capabilities in their daily work.
- A willingness to engage experts from all quarters—other public agencies, private-sector consultants, academia, stakeholders—to assist in improving agency capabilities, analytic tools, and data supporting economic analyses.

Value of Economic Analyses

The case examples, together with follow-on surveys of the literature and interviews with agency personnel, demonstrate two broad classes of benefit of performing economic analyses.

- The first is the direct or tangible benefit of having obtained an economic result that shows the value or merit of a highway investment. This value may be in benefits received by road users or costs avoided by them and by the agency. There is generally a link between economic performance (benefits versus costs) and engineering or technical performance of the highway facility. Monetized benefits help in understanding tradeoffs among competing alternatives. The process of preparing an economic analysis also imposes a discipline to account for all costs and all benefits in as comprehensive and accurate a way as possible.
- The second is the indirect or intangible benefit of encouraging a better decision process within the organization. This benefit and its implications are discussed at length in chapter four, but generally relate to an incentive to identify all realistic alternatives for solution, to maintain focus on the purpose of the proposed investment and avoid "scope creep," to avoid biases toward familiar or traditional options (such as particular paving materials), and to support these objectives through clear agency guidance and communication, backed by the availability of analytic tools and effective data collection and processing.

Resources

Technical resources are available to assist agencies in strengthening their own capabilities in conducting economic analyses. The case examples in chapter three have identified a broad range of engineering economic applications to a number of highway investment analyses occurring at various points of the highway infrastructure life cycle. The case examples illustrate the type and sources of data that can be used in these analyses. Chapter two of this report identifies a number of guides and other literature related specifically to highway transportation. There is also a considerable body of more general literature on engineering economic concepts and methods. Some of the agencies cited in the case examples maintain extensive websites on economic concepts and techniques, or on the use of such methods within their business processes, to produce results that are displayed and discussed on the website. FHWA provides downloadable software to support some of the economic methods discussed in this report.

Current Activities

Current activities are extending economic methods to additional types of highway features, systems, and information (with benefit–cost techniques applied to assess the value of the information). These extensions include other highway features besides pavements and bridges (such as roadside hardware, pavement markings, and traffic signals), ITS devices, Road Weather Information Systems for automated control of anti-icing application or to inform managerial decisions on anti-icing application, electronic toll collection systems, freeway management systems, IntelliDrive deployment for wireless networking of data among road vehicles, road infrastructure, and passengers' personal communications devices, and use of information from full-scale accelerated pavement testing facilities.

European and Canadian Experience

Guidance documents pertaining to economic analysis used by the European Union and Canadian transportation agencies were reviewed in chapter two. As a general comment, these guidelines have a broader scope than comparable U.S. documents, encompassing either several transportation modes (as in the Transport Canada *Guide*) or several infrastructure sectors (as in the European Commission *Guide*). In other respects, however, the economic analyses used by these countries are more circumscribed, with less latitude afforded the performing agency. For example, European analyses are for project appraisals: they tend to be done early in a project's life cycle and are performed for analysis periods of 20 years. Canadian analyses are currently constrained to a discount rate of 10%; although there appears to be recognition that this rate may at some point need to be reviewed; that guidance remains in effect as of the writing of this report. By contrast, the U.S. case examples in chapter three entail analysis periods of 20 years or longer, and discount rates from 3% to 4% at the lower end up to 7% at the higher end. The case examples occur throughout the project life cycle, encompassing project/program development as well as delivery. Apart from these differences, the mechanics of the benefit–cost methods used are similar across all regions. As one example, the U.S., Canadian, and European guides all agree that the economic impacts of highway investments (e.g., job creation and employment increases) are secondary benefits that might not be included in the BCAs of these projects.

European, New Zealand, and Australian experience has also been cited in chapters three and four. Australian research papers have supported the Safety Programming case example in chapter three, and an international scan of performance management practices in Australia, New Zealand, Great Britain, and Sweden has informed the discussion of economic analysis and performance management in chapter four. A major contribution from the European Commission, however, is also described in chapter four: the EVA-TREN project, which has investigated the use of ex-post (or post-construction) analyses of the actual benefit–cost results generated by the completed project as compared with the estimates during project appraisal. The United States does not have a formal policy guideline requiring post-construction analyses, as pointed out by the European sources. However, based on published studies, such a requirement could strengthen future BCAs and improve the quality of data, parameter values, and assumptions. Diligent application of post-construction analyses could conceivably remove many of the reservations some agency personnel have about the assumptions and data in existing economic analyses (refer to the following section on Impediments to Wider Application). Accordingly, post-construction (or ex-post) analyses are included as a research recommendation later in this chapter. The international scan likewise included ex-post analyses as one of the practices recommended to be adopted by U.S. agencies.

IMPEDIMENTS TO WIDER APPLICATION

Several studies by the General Accountability Office (GAO) and FHWA have identified a number of impediments to wider use of EEAs. These are discussed in two categories: weaknesses inherent in the methods themselves, and shortcomings in how the methods are applied.

Weaknesses in the Methods

Concerns about economic methods, BCAs in particular, include the following:

- BCA tallies net benefits in the aggregate, without regard to the equity of the distribution of these benefits.
- Although impacts such as travel-time saved, reductions in emissions, and reductions in accident fatalities and injuries can be monetized, not all researchers may agree on these valuations of impacts.
- Existing models are unable to predict accurately certain key effects of transportation investments; for example, changes in land use, driver behavior, or diversion to alternate routes or modes. This problem is aggravated by the diverse set of models employed by local agencies (which can affect the coordination of state and local policy and project recommendations).

Shortcomings in How Methods Are Applied

Observed shortcomings in how benefit–cost methods are applied include the following:

- The way in which projects are scoped may affect results. One of the GAO studies provided examples with grouping of independent projects, where not all might have survived a BCA individually. Another problem concerned how to account correctly for interactions between complementary projects, where benefits of each project estimated individually might underestimate the total benefit of the projects collectively if they were coordinated.
- A BCA that considers impacts in several areas creates the need to forecast data in these areas, tasks that are subject to uncertainty.

- Benefits that are difficult to quantify may be overlooked or eliminated from the analysis.
- Lack of complete, accurate data may distort forecasts and lead to erroneous results. Surveys of travel demand are getting more difficult to fund and to conduct.
- Certain benefits are double-counted; certain expenditures are counted as benefits. Sometimes future benefits are cited at their nominal value, not discounted to present value. The avoided cost of another project may be counted as a benefit of the project that is being analyzed.
- The definition of alternatives may miss viable options in the current mode or in other modes (e.g., failure to compare a highway project with a transit option).

It can be noted that these shortcomings can be addressed through staff training. There are also methods and procedures to mitigate the risks identified previously; these are discussed in the methodological sections of chapter two and are illustrated in some of the case examples in chapter three.

Assessments of the TIGER Grant Program

The economic analyses that accompanied the TIGER grant applications in 2009 have been of interest to U.S. General Accountability Office (GAO) and FHWA. The program has been proposed as a model for a new type of performance-based or merit-based competitive funding mechanism to replace some of the formulaic funding distributions now used in transportation programs. In its review of the TIGER grant program (together with the High-Speed Intercity Passenger Rail Program), GAO found that benefit–cost assessments were not comprehensive and monetization of benefits varied widely among applications. Many applications also did not follow existing federal guidelines by failing to provide information concerning risk and uncertainty, data limitations, and assumptions inherent in the methodology. The findings of the FHWA review of TIGER grant applications echoed some of these concerns, noting the following errors in the economic analyses:

- Incorrect treatment of some economic development and local construction impacts as project benefits.
- Improper accounting of project costs.
- Unrealistic base cases and project lifetimes.
- Incorrect treatment of discounting and inflation.
- Incorrectly treating initial-year or design-year numbers as a stream of constant annual amounts.
- Incorrectly estimating safety benefits.

The resulting conclusions by the TIGER grant reviewers were the following:

- A wide disparity in the depth and quality of BCAs.
- Insufficient information on expected project outcomes, accompanied by inadequately supported assertions of project benefits.

Survey Responses

Responses to the synthesis survey by those states that do not routinely use economic analysis provided further reasons for the lack of wider application of these methods. The reservations about economic methods included the following:

- Other factors driving investment decisions, including political forces and the need to consider initial project costs rather than life-cycle costs in distributing scarce project funding throughout the state. (The agency making this latter point plans to investigate economic methods in the future, but it would be a difficult concept to sell in the current funding climate.)
- Perceived problems with models and data; for example, questionable assumptions, inadequate available data, and lack of confidence in data (engineering judgment is preferred).
- The complexity and time involved in developing an EEA.
- The perceived tendency of a BCA to favor a single type of safety treatment rather than a more diverse program of multiple types of treatments.
- Litigation concerns with safety programs evaluated through BCA.

RESEARCH SUGGESTIONS

Several gaps in current knowledge and limitations of existing analytic models have been identified throughout this report. These needs for more and better information have been translated into the following recommendations for further research.

1. The errors and deficiencies in the 2009 TIGER grant applications have highlighted weaknesses in nationwide practices regarding the conduct of BCA. More general findings by GAO and others reinforce the need for better understanding of the limitations of engineering economic methods and potential errors in applying these methods. These weaknesses may take on higher priority for correction if the TIGER grant program becomes a model for a future mechanism of federal transportation funding. Several of the errors observed by FHWA in its review of grant applications are basic in nature; for example, erroneous treatment of some economic development and local construction impacts as project benefits, incorrect treatment of discounting and inflation, and unrealistic base cases and project lifetimes. Research is needed to understand the best way in which these types of errors can be corrected, whether through training, peer exchanges, webinars, or development of self-training tools (software), to name a few candidates. Further research would develop the recommended approach as a product for use by transportation agencies.

2. The FHWA review of the TIGER grant applications generated a topic for future research: to understand better the nonroad user benefits and nontraditional impacts of transportation investments. The research could also address the distribution of these benefits and impacts; for example, to public versus private entities; local versus national perspectives; and by income level or population group. This research could structure findings in a manner suitable for use in BCAs of future highway investments.
3. International experience has highlighted the value of ex-post or post-construction BCAs to assess the actual economic results of completed operational projects and compare these values to the estimates made when appraising the project during planning or design. A diligent program of post-construction analyses can improve future benefit–cost calculations and promote the use of higher quality data and better estimates of parameter values. Research is needed to define a recommended structure and protocol for these analyses. A protocol is needed because the post-construction analysis should agree in its computational structure with the original benefit–cost estimate made during project appraisal, and the appraisal estimate must therefore be correctly done. For example, it would not include the types of errors that have been observed in FHWA's and GAO's reviews of the TIGER grant applications. As a final note, the international scan on performance management discussed in chapter four likewise recommended that U.S. agencies consider applying a post-construction, or ex-post, evaluation of their project's actual economic results.
4. Agencies internationally have shown interest in better modeling the variability in travel time, a factor important for high-value and time-critical categories of freight. Research is needed to investigate and develop analytic procedures for this purpose, together with recommendations on setting a value of time for time-critical goods.
5. With the exception of Caltrans' documentation of its value analysis program, there is little information on how long it takes an agency to conduct EEAs. This duration could also vary by the relative experience and familiarity of agency personnel with economic methods, the type of analysis and stage of decision making involved, the status of agency practices in data collection and the degree to which they could support economic analyses, the analytic tools available to assist in these analyses, training and other startup activities needed, and other factors. Research is needed to quantify the expected time commitment that would be needed for preparation and then to conduct these analyses on a routine basis.
6. An alternate approach is to study how agencies that are conversant with economic analyses have integrated these methods within their business processes. Caltrans and WSDOT provide examples of state DOTs that have done this successfully. Such integration implies economy of activities such as data collection and processing that simultaneously serve the requirements of design engineering, traffic engineering, economic analyses, and performance monitoring. Departments that use economic analysis effectively and efficiently assign high value to automating data collection, performing the economic analyses, and reporting results. These agencies also rely on other resources for specialized knowledge and tasks such as consultants, university researchers, and other public agencies. Research is needed to understand the paths by which these agencies transform themselves into effective users of economic methods, and the time, costs, and other resources required. It would also be instructive to identify what human, organizational, and technical factors within this integrated approach would enable agency personnel to exhibit greater team creativity and insight (e.g., in defining alternative solutions for analysis), leading to more cost-effective solutions.
7. Bias in forecasting trends has been observed in research by Flyvbjerg et al. (2005) and Kriger et al. (2006). As an analytic solution, Flyvbjerg proposes a newer method: reference class forecasting. Research is needed to investigate and describe this method as it would be used for the types of analyses prevalent in highway investments: typically, forecasts of travel demand and of revenues on toll roads. The research would include identification of changes in current state DOT practices, if any, that are needed to accommodate the new method, and any issues in realigning data to support the new approach.
8. *TRB Special Report 288* notes the limitations of the current four-step model for travel demand estimation. This model is not inherently behavioral in nature and therefore may not accurately capture road users' responses to the types of policy initiatives now being explored by transportation agencies and political bodies. These current studies might include applications of economic analysis that would require a network capability (e.g., ITS projects, high-occupancy vehicle projects, interchange additions or improvements, and addition of significant new road capacity). Furthermore, existing models begin to break down when disaggregate, individual-level responses must be predicted. The latter requirements would be needed in estimating the time chosen for travel, individual responses to policies such as congestion pricing and telecommuting initiatives, nonmotorized travel, and freight and commercial vehicle movements. Research is needed to develop new travel demand models. Organizational and institutional changes might also need to be researched if model development will affect coordination among the state DOT, MPOs, the federal government, and any intergovernmental agreements.
9. Agencies differ in their characteristics, complicating the problem of transferring knowledge and technology from one agency to another. This issue has been observed by the European Commission as well as in the

United States. An approach to this problem regarding asset management techniques involved creating agency profiles in the form of a series of tables by state DOT, listing factors regarded as important to asset management practice. A similar approach might be applicable to EEA. Research is needed to investigate this idea, or to propose and investigate alternatives for transferring technology and disseminating information among state DOTs and other transportation agencies. The characteristics relevant to profiles related to economic analysis require further thought in the recommended research effort, but helpful starting points are suggested in the structuring of information in chapter two and the case examples in chapter three. These items might include but are not limited to the following:

- Identification of how each agency has implemented relevant federal and national-level guidance, including federal law, FHWA regulations and guidelines, Office of Management and Budget guidelines, AASHTO guidelines, and findings in TRB studies.
- Documentation of relevant state requirements and general agency policies and practices regarding the use of economic methods (e.g., statewide or agency determination of a discount rate; identification of recommended methods; and description of analytic tools already in use).
- Categorization of projects and programs as focal points for EEA. For instance, Table 5 organizes economic analyses by stage of decision making within the project/program life cycle and Table 6 adds the system level(s) at which each is analyzed and the particular economic method used.
- The specific information technology products or analytic tools that are used to conduct each type of analysis indicated earlier. Input data and their sources (with the responsible organizational unit) can also be included.
- Noneconomic factors that are included with economic criteria in informing decisions.
- Particular challenges that agencies have identified in the use of their analyses.

ABBREVIATIONS AND ACRONYMS

Item	Explanation
AADT	annual average daily traffic
ADT	average daily traffic
APT	accelerated pavement testing
ARRA	American Recovery and Reinvestment Act of 2009
AVO	average vehicle occupancy
B/C, B-C, BCA	benefit–cost ratio (or analysis), benefit–cost, benefit–cost analysis [used synonymously with CBA]
BHI	Bridge Health Index [Caltrans]
BMS	bridge management system
Cal-B/C	benefit–cost analysis model used by California DOT
Caltrans	California Department of Transportation
CBA	cost-benefit analysis [used synonymously with benefit–cost analysis]
CDOT	Colorado Department of Transportation
CI	Congestion Index
CPDM	Capital Program Development and Management [an office of WSDOT]
DB	design–build
DL	Detour Length around bridge (NBI Rating Item 019)
DOT	department of transportation
EC	European Commission
EEA	engineering economic analysis
EIA	environmental impact assessment
EU	European Union
EUAC	equivalent uniform annual cost
EVA-TREN	EVAluation of Investment for TRansport and ENergy [European research project]
FDOT	Florida Department of Transportation
GAO	General Accountability Office
GIS	geographic information system
HCM	*Highway Capacity Manual*
HERS	Highway Economic Requirements System
HERS-ST	Highway Economic Requirements System-State Version
HMA	hot-mix asphalt
HOV	high-occupancy vehicle
HSIG	Highway Safety Issues Group [WSDOT]
IIHS	Insurance Institute for Highway Safety
INA	Interstate Network Analysis [model used in network analyses for the PANYNJ]
IRI	International Roughness Index (applied to pavements)
IRR	internal rate of return
ITS	Intelligent Transportation Systems
LCC	life-cycle costs
LCCA	life-cycle cost analysis
Mn/DOT	Minnesota Department of Transportation
MP3, MPPP	Mobility Project Prioritization Process [WSDOT]
MPO	metropolitan planning organization
MTC	Metropolitan Transportation Commission [San Francisco Bay Area]
MTO	Ministry of Transportation of Ontario
MVMT	million vehicle-miles traveled
NBI	National Bridge Inventory
NED	National Economic Development
NJDOT	New Jersey Department of Transportation
NPV	net present value
NYSDOT	New York State Department of Transportation

OMB	Office of Management and Budget
PAITF	Port Authority Interstate Transportation Facilities [owned/operated by PANYNJ]
PANYNJ	Port Authority of New York and New Jersey
PCC	portland cement concrete
PIB	Pontis Improvement Benefit [used by Caltrans]
PMS	pavement management system
PONYNJ	Port of New York and New Jersey
PSRC	Puget Sound Regional Council
RAC	Research Advisory Committee [AASHTO committee comprising member agency representatives]
RCW	Revised Code of Washington
RFP	Request for Proposals
ROC 52	State Highway 52 in Rochester, MN
ROW	right-of-way
SC	NBI Scour Code (Item 113)
SCDOT	South Carolina Department of Transportation
SCIS	Statewide Capital Investment Strategy [New Jersey DOT]
SCOH	[AASHTO's] Standing Committee on Highways
SHOPP	State Highway Operation and Protection Program [Caltrans]
SHSP	Strategic Highway Safety Plan
TEV	Total Element Value [component of Caltrans' bridge analysis]
TIGER	Transportation Investment Generating Economic Recovery
USACE	U.S. Army Corps of Engineers
v/c	volume-capacity ratio
VA	Value Analysis [Value Engineering program of the California DOT]
VE	Value Engineering
VOC	vehicle operating costs
WSDOT	Washington State Department of Transportation
WTSC	Washington Traffic Safety Commission
Y.O.E.	year-of-expenditure

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APPENDIX A

Survey Questionnaire

START OF SURVEY. Use the Tab or arrow keys or mouse clicks to navigate among response fields. Left-click the mouse to enter or remove check-box marks, and type normally in text fields. Please take a moment to read the following.

NCHRP SYNTHESIS TOPIC 41-03 SURVEY QUESTIONNAIRE
ENGINEERING ECONOMIC ANALYSIS PRACTICES FOR HIGHWAY INVESTMENT
FEBRUARY 2010

This NCHRP Synthesis will study current practices in engineering economic analysis by U.S. state transportation agencies to support highway investment decisions. For purposes of this study, engineering economic analysis is defined as the explicit consideration of the multi-year discounted costs (or discounted costs and benefits) of an investment option when evaluating its merits versus those of competing alternatives. Engineering economic methods include, but are not limited to, life-cycle cost analysis, benefit–cost analysis, and measures of cost-effectiveness. These may be applied at one or more stages of a project life cycle, such as planning, project scope development, programming (including ranking and project selection), resource allocation, best-value procurement, project design and development, value engineering, and operation and maintenance.

The purpose of this screening survey is to identify whether your agency uses engineering economic analysis; if so, how; and if not, why. The survey is very short and should take only a few moments to complete.

The survey consists primarily of check-boxes that should be quick to respond to. Each question has an optional Comment field that you can use to explain particular circumstances or add items or topics that may not be included in the prepared tables. If you are not sure of a particular use of engineering economic analysis but are able to provide contact information for someone in your agency who may know, please provide his or her name, phone number, and e-mail address in Question 5.

The survey form can be filled in and submitted electronically. Or, if you prefer, print the form, complete by hand, and post mail to me at the address below. Please return the completed questionnaire via e-mail or post mail by [date] to:

Michael J. Markow, P.E.   E-mail: mjmarkow@comcast.net   Phone (508) 540-5966

43 Rivers End Rd
Teaticket, MA 02536-5858

Please identify your contact information. NCHRP will advertise a link to the online report when it is completed.

Office:

Address:

City: State: ZIP:

Your Name:

Position/Title:

In case of questions, please provide:

Tel: E-mail:

1. Does your agency use engineering economic analyses (e.g., life-cycle cost, benefit–cost, cost-effectiveness) **at all** for highway investment decisions?

   YES ☐ NO ☐

   Comment:

If you checked YES, please respond to Questions 2–5. If you checked NO, please go to Question 6.

2. Please identify investment programs and stages of decision-making in which your agency typically uses engineering economic analyses. Check all that apply.

Investment Program	Planning	Programming	Resource Allocation	Project Design & Development	Bid Evaluation: e.g., for Best Value Procurement	Other—Please Explain Below in Comment	Do Not Use Engr. Economic Methods Here
Pavements	☐	☐	☐	☐	☐	☐	☐
Bridges, Other Structures	☐	☐	☐	☐	☐	☐	☐
Other Asset Preservation	☐	☐	☐	☐	☐	☐	☐
Urban Congestion Relief: Capacity Expansion	☐	☐	☐	☐	☐	☐	☐
Urban Congestion Relief: ITS Strategies	☐	☐	☐	☐	☐	☐	☐
Urban Congestion Relief: Other Operations Improvements	☐	☐	☐	☐	☐	☐	☐
Rural Mobility	☐	☐	☐	☐	☐	☐	☐
Safety	☐	☐	☐	☐	☐	☐	☐
Economic Impact	☐	☐	☐	☐	☐	☐	☐
Environmental Mitigation	☐	☐	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐	☐	☐

Comment:

3. Please indicate the level of the transportation system at which engineering economic analyses are used for each investment program. For this question, "program" level analyses would include analyses of all projects collectively within a single investment program; for example, Pavements, Bridges and Other Structures, ITS Strategies, Safety, etc. "Network" level analyses address the effects of a particular investment (typically in urban congestion relief or rural mobility) that results in spatial or temporal shifts in demand from one link or time period to another.

Investment Program	Project Level	Corridor Level	Program Level	Network Level	Cross-Program Tradeoffs	Other—Please Explain Below in Comment	Do Not Use Engr. Economic Methods Here
Pavements	☐	☐	☐	☐	☐	☐	☐
Bridges, Other Structures	☐	☐	☐	☐	☐	☐	☐
Other Asset Preservation	☐	☐	☐	☐	☐	☐	☐
Urban Congestion Relief: Capacity Expansion	☐	☐	☐	☐	☐	☐	☐
Urban Congestion Relief: ITS Strategies	☐	☐	☐	☐	☐	☐	☐
Urban Congestion Relief: Other Operations Improvements	☐	☐	☐	☐	☐	☐	☐
Rural Mobility	☐	☐	☐	☐	☐	☐	☐
Safety	☐	☐	☐	☐	☐	☐	☐
Economic Impact	☐	☐	☐	☐	☐	☐	☐
Environmental Mitigation	☐	☐	☐	☐	☐	☐	☐
Other:	☐	☐	☐	☐	☐	☐	☐

Comment:

4. For any of these applications of engineering economic analyses, are the economic data and results typically and explicitly used by executive-level managers in their decision-making?

   YES ☐ NO ☐

   Comment:

5. If others in your state DOT can provide more complete information on one or more uses of engineering economic analysis, please provide contact information:

   Name: Tel.: E-mail: Use(s) of engineering economic analysis:

   Name: Tel.: E-mail: Use(s) of engineering economic analysis:

   Name: Tel.: E-mail: Use(s) of engineering economic analysis:

   Name: Tel.: E-mail: Use(s) of engineering economic analysis:

   Name: Tel.: E-mail: Use(s) of engineering economic analysis:

   Name: Tel.: E-mail: Use(s) of engineering economic analysis:

   (Insert additional contacts if needed)

SURVEY IS COMPLETED. THANK YOU FOR PARTICIPATING!

6. You have responded that your agency does not use engineering economic analyses for highway investment decisions. Please provide below the reasons for your not using these analyses, including reservations and concerns about economic methods. Reasons could include, for example, impediments to implementation or perceived problems or deficiencies with these analyses. Please describe these briefly.

SURVEY IS COMPLETED. THANK YOU FOR PARTICIPATING!

APPENDIX B

Interview Guide

[NOTE TO PANEL MEMBERS: This interview guide is based on the case example information called for in the Scope of Work. It is a generic guide, since the details of each state DOT (or other agency) interview will depend on (1) the focus of the particular case example, (2) the role and responsibilities of each interviewee regarding the case example, and (3) the documented information that already exists and can be used in the case example.]

INITIAL INTERVIEWS

The initial interviews—several of which have already been conducted—seek to find out from the primary agency contact what is addressed in the agency's candidate business/decision process, the role of engineering economic analyses within this process, and the type, detail, and maturity of the economic method used. The interviews identify documents that are available to describe the process and the specific economic analyses used. The agency contact may be asked to help gather and provide additional information. These interviews are the basis of recommendations to the panel regarding likely case examples, and to the interviewed agency as to which specific applications of their engineering economic analyses are most beneficial to include in this Synthesis report. The information gathered in these initial interviews enables me to begin case example development.

FOLLOW-UP INTERVIEWS

Follow-up interviews with each agency will look to fill in gaps, flesh out useful details, clarify points, and correct any misconceptions on my part. If warranted, the context of the case example will be strengthened—that is, how does the business/decision process that is supported by engineering economic analyses fit into the agency's overall decision framework for highway investments? At this stage of the Synthesis study, prior to obtaining survey results, I will be conducting these follow-up interviews after coming up with a preliminary case example draft based on the information identified in the initial interviews. Once survey results are obtained, the information gathering and interview process will likely be compressed to move more quickly, since the drafts of the initial set of cases will have established roadmaps and guidelines enabling work to proceed more quickly. To some degree I am "overprogramming" the number of candidate case examples, realizing that (1) some case examples may, on fuller development, turn out not to bear fruit in meeting the study's objectives and therefore need to be downgraded or dropped, and (2) attempts to schedule future interviews with some agencies may not be successful within the time frame needed for Draft 1 completion in June.

The follow-up interviews will address the following items, drawing on items required in the Scope of Work:

- The characteristics of the case example, with an eye toward providing a diverse set of examples in the report, and comments on unique, innovative, or comprehensive aspects.
- Types of highway investments analyzed; e.g., pavement program, bridge projects, durable pavement marking materials options, safety improvement project/program, corridor improvements (e.g., ITS investments, capital projects, managed lanes/pricing, operational improvements).
- Economic methods and elements; e.g., for methods, life-cycle cost, benefit–cost, measure of cost-effectiveness; for elements, agency costs (design, other pre-construction, construction, maintenance, inspection, etc.), agency costs avoided, road user costs or benefits (e.g., savings in travel time and vehicle operating costs, crash/accident reductions), non-user costs or benefits.
- Level at which analyzed; e.g., project, corridor, program (e.g., all pavement projects on a network or sub-network), program tradeoffs (e.g., preservation vs. mobility; pavement vs. bridge), network (involving spatial or temporal shifts in demand due to a particular alternative), or combination of these.
- Stage of asset management *life cycle;* e.g., planning, project scope development, programming (includes ranking and project selection), resource allocation, project design and development, bid evaluation (e.g., in a best-value procurement), post-construction evaluation of outcomes, or combination of these.
- Who performs the analysis, who exercises oversight, and who receives the results.
- How the results are applied to assist decision makers at various organizational levels; what performance measures and decision criteria are used.
- Methods, data, or displays, if any, that capture risk or uncertainty.
- What other measures or decision criteria are used in decision making at various organizational levels, and how these other considerations affect the economic results (e.g., use of "second best" solutions to accommodate geographic equity criteria; superposition of environmental impacts on economic results to yield long-term, more sustainable solutions; incorporation of non-monetary impacts such as network connectivity, land-use impacts, quality and cohesion of affected neighborhoods, or air quality, water quality, and noise impacts).
- Particular resources needed to support economic analyses; e.g., professional staff skills; specialized analytic packages; data availability, feasibility, currency, completeness, and accuracy; public outreach.

APPENDIX C

Screening Survey Participants

State Departments of Transportation	FHWA Division Offices
Arizona DOT	Alabama
Connecticut DOT	California
Florida DOT	Hawaii
Idaho Transportation Department	Iowa
Kansas DOT	Illinois
Maryland State Highway Administration	Minnesota
Maine DOT	New Hampshire
Minnesota DOT	Washington State
Missouri DOT	
Mississippi DOT	
New Jersey DOT	
New Mexico DOT	
Pennsylvania DOT	
South Carolina DOT	
Utah DOT	
Virginia DOT	
Washington State DOT	

APPENDIX D

Selected Federal Requirements for Highway Economic Analyses

The following federal requirements are in addition to those cited in the case studies, and are included to show the breadth of potential applications of engineering economic analyses to highway investments. The compilation is for illustrative purposes only and is not represented to be a complete or exhaustive coverage of all such federal requirements. Please also note that the guidance discussed in this appendix relates only to requirements for economic analyses. Agencies must also comply with other, non-economic requirements on proposed highway investments; e.g., provisions governing environmental protection, mitigation of environmental impacts, and Environmental Justice, to name a few other areas of policy guidance.

CODE OF FEDERAL REGULATIONS, TITLE 23—HIGHWAYS (23 CFR)

CHAPTER I—FEDERAL HIGHWAY ADMINISTRATION, DEPARTMENT OF TRANSPORTATION

SUBCHAPTER E—PLANNING AND RESEARCH

PART 450—PLANNING ASSISTANCE AND STANDARDS

Appendix A to Part 450—Linking the Transportation Planning and NEPA Processes

Background and Overview . . .

I. Procedural Issues . . .

II. Substantive Issues . . .

(b) *Evaluating and Eliminating Alternatives During the Transportation Planning Process:* The evaluation and elimination of alternatives during the transportation planning process can be incorporated by reference into a NEPA document under certain circumstances. In these cases, the planning study becomes part of the NEPA process and provides a basis for screening out alternatives. . . .

. . .

- During the planning Alternatives Analysis, all of the reasonable alternatives under consideration must be fully evaluated in terms of their transportation impacts; capital and operating costs; social, economic, and environmental impacts; and technical considerations; . . .

SUBCHAPTER F—TRANSPORTATION INFRASTRUCTURE MANAGEMENT

PART 505—PROJECTS OF NATIONAL AND REGIONAL SIGNIFICANCE EVALUATION AND RATING

§ 505.9 Criteria for grants.

(a) The Secretary will approve a grant for a Project of National and Regional Significance project only if the Secretary determines, based upon information submitted by the applicant, that the project: . . .

(4) Is justified based on the ability of the project:

(i) To generate national and/or regional economic benefits, as evidenced by, but not limited to: . . .

(C) The demographic and economic characteristics of the area served.

(ii) To allocate public and private costs commensurate with the share of public and private benefits and risks;

(iii) To generate long-term congestion relief that impacts the State, the region, and the Nation, as evidenced by, but not limited to:

(A) Congestion levels, delay, and consequences of delay;

(B) Efficiency and effectiveness of congestion mitigation; and

(C) Travel time reliability.

(iv) To improve transportation safety, including reducing transportation accidents, injuries, and fatalities, as evidenced by, but not limited to, number, rate and consequences of crashes, injuries and fatalities in the affected region and corridor; . . .

§ 505.13 Federal Government's share of project cost.

(a) Based on engineering studies, studies of economic feasibility, and information on the expected use of equipment or facilities, the Secretary shall estimate the project's eligible costs.

SUBCHAPTER G—ENGINEERING AND TRAFFIC OPERATIONS

PART 626—PAVEMENT POLICY

§ 626.2 Definitions.

Unless otherwise specified in this part, the definitions in 23 U.S.C. 101(a) are applicable to this part. As used in this part: Pavement design means a project level activity where detailed engineering and economic considerations are given to alternative combinations of subbase, base, and surface materials which will provide adequate load carrying capacity. Factors which are considered include: Materials, traffic, climate, maintenance, drainage, and life-cycle costs.

§ 627.3 Definitions.

Value engineering. The systematic application of recognized techniques by a multi-disciplined team to identify the function of a product or service, establish a worth for that function, generate alternatives through the use of creative thinking, and provide the needed functions to accomplish the original purpose of the project, reliably, and at the lowest life-cycle cost without sacrificing safety, necessary quality, and environmental attributes of the project.

PART 650—BRIDGES, STRUCTURES, AND HYDRAULICS

§ 650.105 Definitions.

. . . [related to FHWA actions supporting a Unified National Program for Floodplain Management] . . .

(p) Risk analysis shall mean an economic comparison of design alternatives using expected total costs (construction costs plus risk costs) to determine the alternative with the least total expected cost to the public. It shall include probable flood-related costs during the service life of the facility for highway operation, maintenance, and repair, for highway-aggravated flood damage to other property, and for additional or interrupted highway travel.

. . .

Subpart A—Location and Hydraulic Design of Encroachments on Flood Plains

§ 650.115 Design standards.

(a) The design selected for an encroachment shall be supported by analyses of design alternatives with consideration given to capital costs and risks, and to other economic, engineering, social, and environmental concerns.

(1) Consideration of capital costs and risks shall include, as appropriate, a risk analysis or assessment which includes: (i) The overtopping flood or the base flood, whichever is greater, or (ii) The greatest flood which must flow through the highway drainage structure(s), where overtopping is not practicable. The greatest flood used in the analysis is subject to state-of-the-art capability to estimate the exceedance probability.

Subpart H—Navigational Clearances for Bridges

§ 650.807 Bridges requiring a USCG permit.

(a) The USCG has the responsibility (1) to determine whether a USCG permit is required for the improvement or construction of a bridge over navigable waters except for the exemption exercised by FHWA in §650.805 and (2) to approve the bridge location, alignment, and appropriate navigational clearances in all bridge permit applications.

(b) A USCG permit shall be required when a bridge crosses waters which are: (1) tidal and used by recreational boating, fishing, and other small vessels 21 feet or greater in length or (2) used or susceptible to use in their natural condition or by reasonable improvement as a means to transport interstate or foreign commerce. If it is determined that a USCG permit is required, the project shall be processed in accordance with the following procedures.

. . .

(d) The HA [Highway Authority] shall accomplish sufficient preliminary design and consultation during the environmental phase of project development to investigate bridge concepts, including the feasibility of any proposed movable bridges, the horizontal and vertical clearances that may be required, and other location considerations which may affect navigation. At least one fixed bridge alternative shall be included with any proposal for a movable bridge to provide a comparative analysis of engineering, social, economic and environmental benefit and impacts.

§ 650.809 Movable span bridges.

A fixed bridge shall be selected wherever practicable. If there are social, economic, environmental, or engineering reasons which favor the selection of a movable bridge, a cost benefit analysis to support the need for the movable bridge shall he prepared as a part of the preliminary plans.

SUBCHAPTER H—RIGHT-OF-WAY AND ENVIRONMENT

PART 771—ENVIRONMENTAL IMPACT AND RELATED PROCEDURES

§ 771.105 Policy.

. . . [relates to all environmental investigations, reviews, and consultations on a project] . . .

(b) Alternative courses of action should be evaluated and decisions be made in the best overall public interest based upon a balanced consideration of the need for safe and efficient transportation; of the social, economic, and environmental impacts of the proposed transportation improvement; and of national, State, and local environmental protection goals.

PART 772—PROCEDURES FOR ABATEMENT OF HIGHWAY TRAFFIC NOISE AND CONSTRUCTION NOISE

§ 772.9 Analysis of traffic noise impacts and abatement measures.

(a) The highway agency shall determine and analyze expected traffic noise impacts and alternative noise abatement measures to mitigate these impacts, giving weight to the benefits and cost of abatement, and to the overall social, economic and environmental effects.

§ 772.13 Federal participation.

(a) Federal funds may be used for noise abatement measures where: (1) . . . (2) . . . and (3). The overall noise abatement benefits are determined to outweigh the overall adverse social, economic, and environmental effects and the costs of the noise abatement measures.

. . .

(d) There may be situations where severe traffic noise impacts exist or are expected, and the abatement measures listed above are physically infeasible or economically unreasonable. In these instances, noise abatement measures other than those listed in paragraph (c) of this section may be proposed for Types I and II projects by the highway agency and approved by the FHWA on a case-by-case basis when the conditions of paragraph (a) of this section have been met.

§ 772.19 Construction noise.

The following general steps are to be performed for all Types I and II projects:

(a) . . .

(b) Determine the measures which are needed in the plans and specifications to minimize or eliminate adverse construction noise impacts to the community. This determination shall include a weighing of the benefits achieved and the overall adverse social, economic and environmental effects and the costs of the abatement measures.

UNITED STATES CODE, TITLE 23—HIGHWAYS (23 USC) CHAPTER 1—FEDERAL-AID HIGHWAYS

Sec. 138. Preservation of parklands

Study of Alternative Transportation Modes in National Park System

Pub. L. 102-240, title I, Sec. 1050, Dec. 18, 1991, 105 Stat. 2000, provided that:

(a) In General.—Not later than 12 months after the date of the enactment of this Act [Dec. 18, 1991], the Secretary, in consultation with the Secretary of the Interior, shall conduct and transmit to Congress a study of alternative transportation modes for use in the National Park System. In conducting such study, the Secretary shall consider (1) the economic and technical feasibility, environmental effects, projected costs and benefits as compared to the costs and benefits of existing transportation systems, and general suitability of transportation modes that would provide efficient and environmentally sound ingress to and egress from National Park lands; and (2) methods to obtain private capital for the construction of such transportation modes and related infrastructure.

Sec. 602. Determination of eligibility and project selection

. . .

(b) Selection Among Eligible Projects.—

(1) Establishment.—The Secretary shall establish criteria for selecting among projects that meet the eligibility requirements specified in subsection (a).

(2) Selection criteria.—

(A) In general.—The selection criteria shall include the following:

(i) The extent to which the project is nationally or regionally significant, in terms of generating **<u>economic benefits</u>**, supporting international commerce, or otherwise financing the national transportation system.

PROJECTS OF NATIONAL AND REGIONAL SIGNIFICANCE

Pub. L. 109-59, title I, Sec. 1301, Aug. 10, 2005, 119 Stat. 1198, as amended by Pub. L. 110-244, title I, Sec. 103(a), June 6, 2008, 122 Stat. 1578, provided that:

(a) Findings.—Congress finds the following:

(1) Under current law, surface transportation programs rely primarily on formula capital apportionments to States.

(2) Despite the significant increase for surface transportation program funding in the Transportation Equity Act of the 21st Century [Pub. L. 105-178, see Tables for classification], current levels of investment are insufficient to fund critical high-cost transportation infrastructure facilities that address critical national economic and transportation needs.

(3) Critical high-cost transportation infrastructure facilities often include multiple levels of government, agencies, modes of transportation, and transportation goals and planning processes that are not easily addressed or funded within existing surface transportation program categories.

(4) Projects of national and regional significance have national and regional benefits, including improving economic productivity by facilitating international trade, relieving congestion, and improving transportation safety by facilitating passenger and freight movement.

(5) The benefits of projects described in paragraph (4) accrue to local areas, States, and the Nation as a result of the effect such projects have on the national transportation system.

. . .

(2) Criteria for grants.—The Secretary may approve a grant under this section for a project only if the Secretary determines that the project—

(A) is based on the results of preliminary engineering;

(B) is justified based on the ability of the project—

(i) to generate national economic benefits, including creating jobs, expanding business opportunities, and impacting the gross domestic product;

(ii) to reduce congestion, including impacts in the State, region, and Nation;

(iii) to improve transportation safety, including reducing transportation accidents, injuries, and fatalities;

(iv) to otherwise enhance the national transportation system; and . . .

NATIONAL CORRIDOR PLANNING AND DEVELOPMENT PROGRAM

Pub. L. 105-178, title I, Sec. 1118, June 9, 1998, 112 Stat. 161, provided that: . . .

(d) Corridor Development and Management Plan. — A State or metropolitan planning organization receiving an allocation under this section shall develop, and submit to the Secretary for review, a development and management plan for the corridor or a usable component thereof with respect to which the allocation is being made. Such plan shall include, at a minimum, the following elements:

(1) A complete and comprehensive analysis of corridor costs and benefits.

. . .

TRAFFIC CONTROL SIGNALIZATION DEMONSTRATION PROJECTS: REPORTS TO SECRETARY OF TRANSPORTATION; REPORT TO CONGRESS

Section 146 of Pub. L. 94-280 provided that:

(a) The Secretary of Transportation is authorized to carry out traffic control signalization demonstration projects designed to demonstrate through the use of technology not now in general use the increased capacity of existing highways, the conservation of fuel, the decrease in traffic congestion, the improvement in air and noise quality, and the furtherance of highway safety, giving priority to those projects providing coordinated signalization of two or more intersections. Such projects can be carried out on any highway whether on or off a Federal-aid system.

(b) There is authorized to be appropriated to carry out this section of the Highway Trust Fund, not to exceed $40,000,000 for the fiscal year ending September 30, 1977, and $40,000,000 for the fiscal year ending September 30, 1978.

(c) Each participating State shall report to the Secretary of Transportation not later than September 30, 1977, and not later than September 30 of each year thereafter, on the progress being made in implementing this section and the effectiveness of the improvements made under it. Each report shall include **an analysis and evaluation of the benefits resulting from such projects comparing an adequate time period before and after treatment in order to properly assess the benefits occurring from such traffic control signalization.** The Secretary of Transportation shall submit a report to the Congress not later than January 1, 1978, on the progress being made in implementing this section and an evaluation of the benefits resulting therefrom.

STUDY OF CMAQ PROGRAM

Pub. L. 105-178, title I, Sec. 1110(e), June 9, 1998, 112 Stat. 144, provided that:

. . .

(E) assess the effectiveness, including the quantitative and non-quantitative benefits, of projects funded under the program and include, in the assessment, an estimate of the cost per ton of pollution reduction;

(F) assess the cost-effectiveness of projects funded under the program with respect to congestion mitigation;

(G) compare—

(i) the costs of achieving the air pollutant emissions reductions achieved under the program; to

(ii) the costs that would be incurred if similar reductions were achieved by other measures, including pollution controls on stationary sources;

. . .

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. . .

(f) Each State shall establish an evaluation process approved by the Secretary, to analyze and assess results achieved by safety improvement projects carried out in accordance with procedures and criteria established by this section. Such evaluation process shall develop cost-benefit data for various types of corrections and treatments which shall be used in setting priorities for safety improvement projects.

. . .

(3) Major projects.—The Secretary may require more than 1 analysis described in paragraph (2) for a major project described in subsection (h).

(4) Requirements.—Analyses described in paragraph (1) for a bridge project shall

(A) include bridge substructure requirements based on construction material; and

(B) be evaluated—

(i) on engineering and economic bases, taking into consideration acceptable designs for bridges; and

(ii) using an analysis of life-cycle costs and duration of project construction.

. . .

(f) Life-Cycle Cost Analysis.—

(1) Use of life-cycle cost analysis.—The Secretary shall develop recommendations for the States to conduct life-cycle cost analyses. The recommendations shall be based on the principles contained in section 2 of Executive Order No. 12893 and shall be developed in consultation with the American Association of State Highway and Transportation Officials. The Secretary shall not require a State to conduct a life-cycle cost analysis for any project as a result of the recommendations required under this subsection.

(2) Life-cycle cost analysis defined.—In this subsection, the term "life-cycle cost analysis" means a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, user costs, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment.

. . .

USE OF RECYCLED PAVING MATERIAL

Section 1038 of Pub. L. 102-240, as amended by Pub. L. 104-59, title II, Sec. 205(b), title III, Sec. 327, Nov. 28, 1995, 109 Stat. 577, 592, provided that:

. . .

(5) Report.—Not later than 18 months after the date of the enactment of this Act [Dec. 18, 1991], the Secretary and the Administrator shall transmit to Congress a report on the results of the studies conducted under this subsection, including a detailed analysis of the economic savings and technical performance qualities of using such recycled materials in federally assisted highway projects and the environmental benefits of using such recycled materials in such highway projects in terms of reducing air emissions, conserving natural resources, and reducing disposal of the materials in landfills.

. . .

TRAFFIC CONTROL SIGNALIZATION DEMONSTRATION PROJECTS; REPORTS TO SECRETARY OF TRANSPORTATION; REPORT TO CONGRESS

Section 146 of Pub. L. 94-280 provided that:

. . .

(c) Each participating State shall report to the Secretary of Transportation not later than September 30, 1977, and not later than September 30 of each year thereafter, on the progress being made in implementing this section and the effectiveness of the improvements made under it. Each report shall include an analysis and evaluation of the benefits resulting from such projects comparing an adequate time period before and after treatment in order to properly assess the benefits occurring from such traffic control signalization

. . .

Abbreviations used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation