

Economic Analysis Primer



U.S. Department
of Transportation

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NOTE FROM THE DIRECTOR

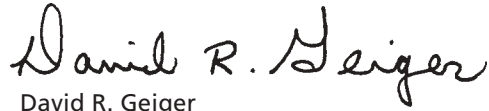
Office of Asset Management, Federal Highway Administration

How do we know if a highway project is worth undertaking, when it should be done, or what is the most cost-effective means of accomplishing it? What will the effects of the project be on the regional economy? These are among the questions that economic analysis will help to answer when it is coordinated with transportation planning, engineering, environmental review, budgeting, and policy making.

Although the idea of comparing the benefits and costs of transportation projects on a dollar-to-dollar basis has long appealed to decision makers, the application of economic analysis to such projects is often neglected in practice. Agencies may believe that transportation benefits and costs are too hard to quantify and value, or too subject to uncertainty to provide meaningful guidance. Fortunately, an expanding research base on economic methods and values, improved modeling of traffic and uncertainty, and more powerful desktop computers have made the widespread use of economic analysis for highway projects an attainable goal.

This primer is intended to provide a foundation for understanding the role of economic analysis in highway decision making. It is oriented toward State and local officials who have responsibility for assuring that limited resources get targeted to their best uses and who must account publicly for their decisions. It presents economic analysis as an integral component of a comprehensive infrastructure management methodology that takes a long-term view of infrastructure performance and cost. The primer is non-technical in its descriptions of economic methods, but it encompasses a full range of economic issues that are of potential interest to transportation officials.

The issuance of this primer is in keeping with the Federal Highway Administration's commitment to provide technical assistance, tools, and training to support State and local transportation agencies in their critical role of accommodating the Nation's need for safe and efficient transportation.

A handwritten signature in black ink that reads "David R. Geiger". The signature is written in a cursive style with a large initial 'D' and 'G'.

David R. Geiger
Director, Office of Asset Management

INTRODUCTION

This primer begins by explaining what economic analysis is and why it is important to transportation decision making. The narrative proceeds to some of the fundamental concepts required for the economic analysis of projects (inflation and discounting) and then describes actual applications of economic analysis methodology, especially life-cycle cost analysis and benefit-cost analysis. An issue critical to accurate calculations of project net benefits—forecasting traffic growth—is addressed after the treatment of benefit-cost analysis.

Risk analysis can greatly improve the usefulness of economic analysis to decision makers. This subject is handled in a separate section, although it applies to all of the economic methods described in this primer.

Economic impact analysis is discussed at the end of the primer. It complements benefit-cost analysis by revealing how the direct transportation benefits and costs of highway projects (such as reduced travel time) manifest themselves in the form of new jobs, business growth, tourism, and income. Such information is often important for making decisions about highway projects.

ROLE OF ECONOMIC ANALYSIS IN HIGHWAY DECISION MAKING

Economic analysis is a critical component of a comprehensive project or program evaluation methodology that considers all key quantitative and qualitative impacts of highway investments. It allows highway agencies to identify, quantify, and value the economic benefits and costs of highway projects and programs over a multiyear timeframe. With this information, highway agencies are better able to target scarce resources to their best uses in terms of maximizing benefits to the public and to account for their decisions.

Economic analysis can inform many different phases of the transportation decision making process (see box, page 8). It can assist engineers in the development of more cost-effective designs once a decision has been made to go forward with a project. In planning, it can be applied to basic cost and performance data to screen a large number of potential project alternatives, assisting in the development of program budgets and areas of program emphasis. Similarly, economic analysis can play a critical role in screening alternatives to accomplish a specific project, providing information for the environmental assessment process.

Although economic analysis can provide valuable information for the environmental assessment of a project or program, it is neither a substitute for nor a required component of the environmental assessment process. Nothing in this primer about economic analysis should be interpreted as supplementing, overriding, or otherwise modifying Federal regulations and guidance on environmental assessments conducted under the National Environmental Policy Act of 1969, the Clean Air Act as amended in 1990, and other laws pertaining to environmental review of transportation projects.

STATUS OF ECONOMIC ANALYSIS

The application of economic analysis to highway investments is not a new concept. The American Association of State Highway Officials published information on road user benefit analysis in 1952, showing that economic methods and procedures for highway appraisal were well understood and described 50 years ago. Of course, significant progress has been made since that time in areas as diverse as modeling of future traffic flows; estimating the consequences of highway projects on jobs and incomes; and the application of computer technologies to support improved economic methods.

Today, many States and metropolitan planning organizations (MPOs) and some local governments use economic tools in some capacity. There is, however, much diversity in application. Most agencies will occasionally quantify the life-cycle costs or net benefits of projects or investigate their economic impacts on communities. Only a minority of agencies, however, regularly measure project net benefits in monetary terms. Also, most agencies do not consider the full range of costs and benefits when conducting their analyses. In general, there is significant potential for the broader application of economic methods to highway decision making.

ROLE OF THE FEDERAL HIGHWAY ADMINISTRATION

FHWA has a long tradition of promoting the application of economic analysis to highway project planning, design, construction, preservation, and operation. FHWA has strongly encouraged the use of life-cycle cost applications as part of its pavement design and preservation initiatives, as well as in the Value Engineering program. FHWA has also developed more advanced economic tools that measure benefits and costs of highway investments, including the program-level Highway Economic Requirements System model described later in this primer.

As part of its long-term commitment to improving highway investment and management practices, FHWA will continue to develop and advance economic tools and guidance. A major new impetus for this effort is the promotion of Transportation Asset Management for use by transportation agencies. Transportation Asset Management is a strategic approach to maximize the benefits from resources used to operate, expand, and preserve the transportation infrastructure over the long term. The use of economic analysis to compare costs and benefits in dollar terms over multiyear periods provides vital information to this and other comprehensive infrastructure management strategies.

BENEFITS OF USING ECONOMIC ANALYSIS

Among the benefits of applying economic analysis to highway projects are the following:

- *Cost-Effective Design and Construction.* Economic analysis can inform highway agencies as to which of several project designs can be implemented at the lowest life-cycle cost to the agency and the lowest work zone delay cost to the traveler, and it can identify the best affordable balance between these costs.
- *Best Return on Investment.* Economic analysis can help in planning and implementing transportation programs with the best rate of return for any given budget, or it can be used to help determine an optimal program budget.
- *Understanding Complex Projects.* In a time of growing public scrutiny of new and costly road projects, highway agencies and other decision makers need to understand the true benefits of these projects, as well as the effects that such projects will have on regional economies. This information is often very helpful for informing the environmental assessment process.
- *Documentation of Decision Process.* The discipline of quantifying and valuing the benefits and costs of highway projects also provides excellent documentation to explain the decision process to legislatures and the public.

ECONOMIC FUNDAMENTALS

The most basic economic questions that people face in their day-to-day personal and business lives involve the tradeoffs between dollars earned, spent, or invested today and those dollars they hope to earn, spend, or invest in the future. Such tradeoffs must also be considered when evaluating highway investments.

ACCOUNTING FOR DOLLARS OVER THE PROJECT LIFE CYCLE

A given project will generate costs and benefits over its entire service life cycle. During construction, it will generate mostly costs. Once in service, it will generate mostly benefits, although some costs continue due to maintenance, periodic rehabilitation, and operational activities. In many cases, benefits will build over time as traffic levels increase. These benefits and costs can be presented in dollar terms for each year of the project's life cycle. Figure 1 illustrates a typical time series of costs and benefits.

Comparison of benefits to costs over the project life cycle would be a simple issue of summation except for one problem: the value of a dollar changes over time. In particular, a dollar that an individual or agency will spend

or earn in the future is almost always worth less to them today than a dollar they spend or earn now. This changing value of the dollar must be understood and quantified to enable meaningful comparisons of multiyear dollar streams.

Two separate and distinct factors account for why the value of a dollar, as seen from the present, diminishes over time. These factors are inflation and the time value of resources.

INFLATION

Causes and Measurement

Inflation is said to occur when the prices of most goods and services in the economy are rising by some degree over time—also referred to as “general inflation.” Economists believe that inflation is usually caused when there is more demand expressed for goods and services in the economy than there is supply of those same goods and services at current prices. To produce the goods and services needed to meet demand, firms must pay more for the inputs (including labor and raw materials) needed to produce the goods and services. For example, it might be necessary to pay overtime premiums to existing workers or pay higher wages to attract new workers. These higher costs get passed on to consumers in the form of higher prices for the goods and services produced; consumers in turn seek higher wages to pay for the higher priced goods and services, and so on, in a circular manner.

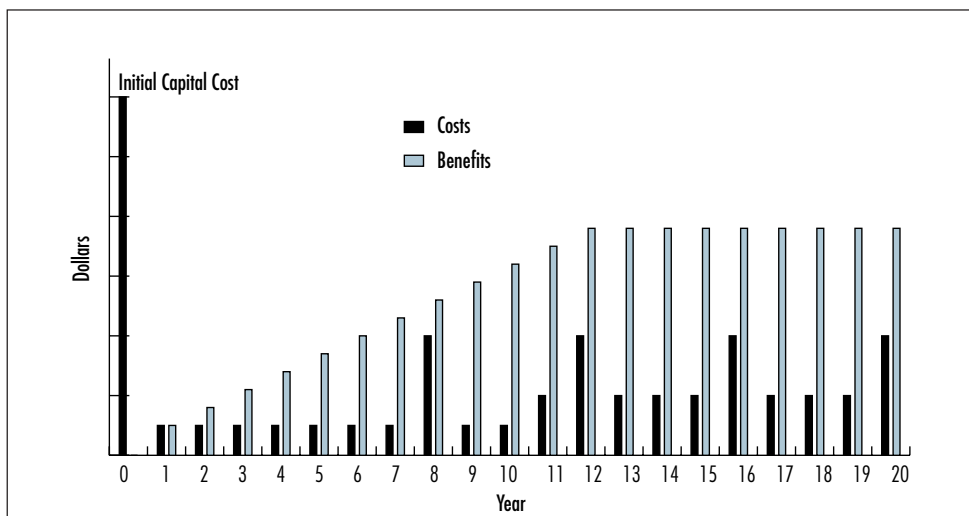


FIGURE 1. Time Series of Costs and Benefits

Economists usually measure inflation by comparing the price of groupings or “market baskets” of goods and services from year to year. The prices of some goods and services in the grouping will go up, the prices of others may go down—it is the overall price level of the grouping that captures the effect of inflation. A price or inflation index is constructed by dividing the price of the grouping in each year by its price in a fixed base year, and multiplying the result by 100. The change in the index value from year to year reveals the trend and scale of inflation. The Consumer Price Index (CPI) is probably the best-known price or inflation index to most Americans, but there are many others.

Just as inflation is encountered in the general economy, the costs of highway projects tend to rise over time as a result of inflation. This is because highway projects must compete for many of the same resources (such as labor or steel) that other sectors of the economy require.

FHWA measures trends in highway construction costs by a Bid Price Index (BPI, also called the Federal-Aid Highway Construction Cost Composite Index). The BPI is constructed from the unit prices for materials in actual highway project bids, compiled from reports of State awards for Federal-aid contracts of \$500,000 or greater. Inflation in construction costs is measured by the changes



in these unit prices from year to year. Many States produce their own highway cost indices to reflect local conditions and practices.

Engineering News-Record (ENR) publishes both a Construction Cost Index and Building Cost Index that are widely used in the construction industry. ENR also publishes various materials prices for 20 U.S. cities and two Canadian cities. Other indices include the Turner Construction Co. Composite Index and the R.S. Means Heavy Construction Cost Index.

Dollars from one year can be converted into equivalent dollars of another year (as measured by purchasing power) by using price indices to add or remove the effects of inflation (see box). Dollars from which the inflation component has been removed are known as “real,” “constant,” or “base year” dollars. A real dollar is able to buy the same amount of goods and services in a future year as in the base year of the analysis. Dollars that include the effects of inflation are known as “nominal,” “current,” or “data year” dollars. A nominal dollar will typically buy a different amount of goods and services in each year of the analysis period.

When to Adjust for Inflation

In the case of economic analysis of investments by a public agency, it is best practice to forecast life-cycle costs and benefits of a project without inflation (i.e., in real or base year dollars). Inflation is very hard to predict, particularly more than a few years into the future. More importantly, if inflation is added to benefits and costs projected for future years, it will only have to be removed again before these benefits and costs can be compared in the form of dollars of any given base year.

The essential time to consider inflation is when the project budget is being prepared, after economic analysis has shown the project to be economically viable. Future year or multiyear project budgets are appropriated in future year dollars rather than base year dollars. Failure to account for inflation in project budgets will almost always result in too few future year dollars being set aside to complete the projects (leading to public perceptions of cost overruns and mismanagement) and will hurt the agency’s ability to program future projects. Also, if historical cost data are being used to develop base year cost estimates for a project, the historical cost data should be adjusted to base year dollars using an inflation index.

FORMULAS FOR ADJUSTING FOR INFLATION

The use of price or inflation indices to adjust for inflation is relatively straightforward.

To remove inflation (i.e., convert data year, nominal dollars into base year, real dollars):

$$\text{Dollars}_{\text{base year}} = \text{Dollars}_{\text{data year}} \times \text{Price Index}_{\text{base year}} / \text{Price Index}_{\text{data year}}$$

To add inflation (i.e., convert base year, real dollars into data year, nominal dollars):

$$\text{Dollars}_{\text{data year}} = \text{Dollars}_{\text{base year}} \times \text{Price Index}_{\text{data year}} / \text{Price Index}_{\text{base year}}$$

For instance, assume that the base year for an analysis is 1999. If a highway structure cost \$100,000 to build in 1992, how much would it have cost in base year 1999 dollars (all else being equal)? The answer (based on the structure price information contained in the Federal Highway Administration's Bid Price Index [BPI]) would be:

$$\text{\$100,000}_{\text{data year (1992)}} \times \text{138.3}_{\text{BPI structures index (1999)}} / \text{108.4}_{\text{BPI structures index (1992)}}$$

or \$127,583 base year 1999 dollars. Similarly, a base year dollar can be converted to an equivalent amount of purchasing power for any other year based on the second formula.

Historical price index data can be used to adjust for inflation in years prior to and including the present. When adjusting future, multiyear project budgets to allow for possible inflation, the analyst should consult a financial or economic expert to develop reasonable estimates of anticipated future price growth.

When adjusting for inflation, an index appropriate for the task should be used. For doing cost or budget estimates, this index will often be the State version of the BPI. In a few cases, the analyst may believe that a resource's cost has grown or will grow much more rapidly than the rate of inflation. For instance, right-of-way costs may soar due to real estate speculation in anticipation of a new road. In such cases, the analyst should work with experts to determine how much the real price of the resource will change over time and include this adjusted price in the economic analysis. It is good practice to consult with an economist whenever an issue arises over the appropriate treatment of inflation.

TIME VALUE OF RESOURCES

Most people have a day-to-day familiarity with inflation. They are less familiar, however, with the separate and distinct concept of the time value of resources. Yet this latter concept is the backbone of economic analysis of transportation projects and of the Nation's financial system in general.

The time value of resources is also referred to as the time value of money or the opportunity cost (or value) of resources. It reflects the fact that there is a cost associated with diverting the resources needed for an investment from other productive uses or planned consumption within the economy. This cost is equal to the economic return that could be earned on the invested resources (or the dollars used to buy them) in their next best alternative use. Equivalently, the time value of resources can be interpreted as the amount of compensation that must be paid to people to induce them not to consume their resources in the current year, but rather to make them available for future investment.

The Role of the Discount Rate

The time value of resources is measured by an annual percentage factor known as the discount rate. The discount rate has a positive value whether or not there is inflation in the economy, as illustrated by the following example.

Assume that for the next 20 years no general inflation is expected. That is, \$100 would buy the same (or a comparable) market basket of goods and services in 20 years that it will buy today. In this environment, would a person expect to be able to borrow money at zero interest? Would that person lend money to someone else at zero interest? The answer to both questions, at least for most people, is “no.” Money can always be invested now to earn a return (e.g., in real estate or a profitable enterprise). Alternatively, it can be spent on something a person wants now (e.g., a nicer house), as opposed to having to wait to buy it in the future.

Thus, people must be compensated for making money available even if there is no inflation. If, for example, people require at least \$105 after one year as compensation for making \$100 available today, then they are equating the value of \$105 after one year to \$100 in the present. Put another way, the “present value” of \$105 one year from now is \$100. The annual rate of return (5 percent in this example) in compensation for the time value of resources is the discount rate.

If an analyst knows the appropriate discount rate, he or she can calculate the “present value” of any sum of resources or money to be spent or received in the future. The application of the discount rate to future sums to calculate their present value is known as “discounting” (see box). Through discounting, different investment alternatives can be objectively compared based on their respective present values, even though each has a different stream of future benefits and costs.

FORMULA FOR DISCOUNTING

The standard formula for discounting is as follows:

$$PV = [1/(1+r)^t] A_t$$

where:

- PV = present value at time zero (the base year);
- r = discount rate;
- t = time (year); and
- A = amount of benefit or cost in year t .

The formula above is the most basic calculation of present value. The term

$$1 / (1+r)^t$$

which incorporates the discount rate “ r ” is called the discount factor. Multiplying a future sum by the appropriate discount factor for that future year will yield the present value of that sum at time zero (e.g., the year in which the analysis is being done).

Of course, most highway projects generate costs and benefits over their entire life cycles. This entire series of costs and benefits must be discounted to the present by multiple applications of the PV formula for each applicable year of the life cycle (see formula below). These discounted values are then summed together (as represented by Σ) for each year of the life-cycle analysis period (“N”) to yield an overall present value. The formula for doing this is as follows:

$$PV = \sum_{t=1}^N [1/(1+r)^t] A_t$$

The present value of a series of numbers is often described as the “net present value,” reflecting the fact that the discounted sum often represents the net value of benefits after costs are subtracted from them.

Selecting a Discount Rate

As a rule of best practice, economic analysis should be done in real terms, i.e., using dollars and discount rates that do not include the effects of inflation. A real discount rate can be estimated by removing the rate of inflation (as measured by a general price index such as the CPI) from a market (or nominal) interest rate for government borrowing. The selected market rate for government borrowing should be based on government bonds with maturities comparable in length to the analysis period used for the economic analysis. Real discount rates calculated in this manner have historically ranged from 3 percent to 5 percent—the rates most often used by States for discounting highway investments (see box).

The U.S. Office of Management and Budget (OMB) currently requires U.S. Federal agencies to use a 7 percent real discount rate to evaluate public investments and regulations.¹ Federal agencies may use lower rates (based on inflation-adjusted Federal borrowing costs) for life-cycle cost analysis. In January 2003, OMB reported a 10-year real discount rate of 2.5 percent and a 30-year rate of 3.2 percent, based on current Federal borrowing costs. These latter rates reflect historically low costs of government borrowing.

In times of budget shortfalls, an agency may increase its discount rate to reflect the higher opportunity cost of

such funds. The agency should consider, however, that the discount rate applies over the life of the project, and adjusting the discount rate to reflect short-term funding fluctuations may distort the value of long-term benefits and costs. An agency may also increase its discount rate to account for project risk. FHWA recommends, however, that risk be treated directly with risk analysis tools rather than through adjustments to the discount rate (see section on Risk Analysis, page 30).

THE DISCOUNT RATE MATTERS

The selection of an appropriate discount rate is important. For example, the present value of \$1,000 of benefits received 30 years in the future is \$412 when discounted at 3 percent per year, \$231 when discounted at 5 percent, but only \$57 when discounted at 10 percent. Thus, present values of costs and benefits 30 years in the future can be changed by more than a factor of 5 depending on the discount rate used. Due to the importance of the discount rate, care should be taken to select one that reflects a State's actual time value of resources.

¹ This rate is adjusted occasionally. OMB has announced that significant changes in the 7 percent rate will be reflected in future guidance to Federal agencies.



LIFE-CYCLE COST ANALYSIS

The first systematic economic means of comparing highway investments that will be discussed in this primer is called life-cycle cost analysis (LCCA). It applies the discount rate to the life-cycle costs of two or more alternatives to accomplish a given project or objective, enabling the least cost alternative to be identified.

WHEN TO USE LIFE-CYCLE COST ANALYSIS

LCCA is applied when an agency must undertake a project and is seeking to determine the lowest life-cycle-cost (i.e., most cost-effective) means to accomplish the project's objectives. LCCA enables the analyst to make sure that the selection of a design alternative is not based solely on the lowest initial costs, but also considers all the future costs (appropriately discounted) over the project's usable life.

LCCA is used appropriately only to select from among design alternatives that would yield the same level of performance or benefits to the project's users during normal operations. If benefits vary among the design alternatives (e.g., they would accommodate different levels of traffic), then the alternatives cannot be compared solely on the basis of cost. Rather, the analyst would need to employ benefit-cost analysis (BCA), which measures the monetary value of life-cycle benefits as well as costs (BCA is discussed at length in the next section of this primer, page 17). Accordingly, LCCA should be viewed as a distinct, cost-only subset of BCA. Even with these restrictions, however, LCCA has many useful applications (see box).

PROCEDURES FOR BEST RESULTS

Best-practice LCCA requires that the objective(s) of the project be clearly defined, assumptions about future usage be clearly stated, and all reasonable means of accomplishing the same objective(s) be evaluated. Only when all reasonable alternatives are evaluated can the analyst be confident that LCCA will reveal the most cost-effective transportation solution.

USEFUL APPLICATIONS OF LIFE-CYCLE COST ANALYSIS

Life-cycle cost analysis (LCCA) has applications for many areas of interest to State and local transportation agencies. Common applications of LCCA include the following:

- Designing, selecting, and documenting the most affordable means of accomplishing a specified project or objective. For instance, if a bridge must be replaced, LCCA can be used to select the replacement option that would cost the least over the expected life of the bridge.
- Evaluating pavement preservation strategies. The costs of each strategy can be evaluated relative to the expected effects it will have on delaying the costs of expensive rehabilitations or reconstructions.
- Value engineering (VE). Value engineering must be applied to all Federal-aid highway projects on the National Highway System with an estimated cost of \$25 million or more. Among other requirements, the VE team must consider the lowest life-cycle-cost means of accomplishing a project.
- Project planning and implementation, especially the use and timing of work zones. LCCA allows the analyst to balance higher agency and/or contractor costs associated with off-peak work hours against reduced traveler delay costs associated with fewer work zones during peak periods.

Note that these applications involve comparing alternatives with identical levels of service (e.g., pavement preservation or replacement strategies for an existing two-lane road). Were the level of service different among alternatives being compared, a strict comparison of life-cycle costs using LCCA would not be appropriate. Rather, the correct economic tool would be benefit-cost analysis.

In LCCA, the analyst applies the discount rate to the costs from each year of the project’s life cycle. This yields the present value of the project’s cost stream. Because the costs of competing alternatives can only be compared fairly if the alternatives yield the same benefits, the analyst must compare the project alternatives over the same operational time period, known as the study or analysis period. As a rule of thumb, the analysis period should be long enough to incorporate all, or a significant portion, of each alternative’s life cycle, including at least one major rehabilitation activity for each alternative (typically a period of 30 to 40 years for pavements, but longer for bridges). In some cases, an analysis period long enough to capture the life cycle of one alternative may require that a shorter-lived alternative be repeated during that period.

It is important to capture all costs that differ among the alternatives being compared. Where uncertainty associated with future costs is identified, the analyst should assess its potential impact on the alternative using appropriate risk analysis methods (see section on Risk Analysis, page 30).

COST ELEMENTS TO INCLUDE

Costs associated with construction, rehabilitation, and maintenance activities of each alternative being compared should be identified, monetized, and then discounted to their present value. Table 1 lists the cost categories and elements generally included in LCCA.

TABLE 1. Costs Typically Considered in Life-Cycle Cost Analysis

Agency Costs
Design and engineering
Land acquisition
Construction
Reconstruction/Rehabilitation
Preservation/Routine maintenance
User Costs Associated With Work Zones
Delays
Crashes
Vehicle operating costs

There may be cases where some of the cost elements shown in Table 1 need not be quantified when comparing alternatives using LCCA. This is because alternatives that accomplish identical objectives (a requirement when using LCCA) often have many costs in common (e.g., they occupy the same right-of-way and require the same design effort). Costs that are identical (in terms of both their amount and when they occur) among all alternatives need not be quantified, as they will “wash out” in a cost comparison. In short, the analyst should focus only on those costs that vary among alternatives.

Of agency cost elements, construction and rehabilitation typically vary the most among alternatives and must be quantified. Routine maintenance costs may or may not vary significantly. Different alternatives may be evaluated with and without preservation treatments of different types. The BCA section of this primer (page 17) contains more information about quantifying agency costs.

“User costs” are those costs pertaining to a project alternative that travelers, rather than the agency, would incur. User costs often vary significantly among alternatives, largely due to different work zone requirements for the construction and rehabilitation activities associated with each alternative. Using available models, the analyst can estimate user costs associated with travel delay at work zones with some accuracy. Vehicle operating costs (VOC) in work zones can also be estimated, but these are typically small relative to those for travel delay. Work zones can affect safety, but work zone crash costs are sometimes omitted from LCCA due to inconclusive data about crash rates and severities for specific work zone configurations and traffic management strategies.

User costs under normal facility operating conditions should not vary significantly among the alternatives being compared using LCCA. Significant differences in such costs among alternatives would suggest that the levels of performance (and therefore the benefits) of the alternatives are not equal and that BCA should be used instead of LCCA.

USER COST CONTROVERSY

Work zones temporarily reduce capacity and can create significant delays to travelers. Best-practice LCCA should reflect work zone user costs along with agency costs. Many agencies, however, have been reluctant to include work zone user costs with agency costs in LCCA calculations. Project design alternatives that reduce work zone user costs often entail higher agency expenses—not welcome in times of tight highway budgets. This is particularly true because agency costs appear in agency budgets and user costs do not. Agencies may also perceive that there is too much uncertainty in valuing user travel delay time.

It is inadvisable, however, not to assign a value to work zone travel delay when using economic analysis methods such as LCCA or BCA. Highway agencies build roads to accommodate users. If an agency cites benefits to users as a justification for spending agency dollars to build or rehabilitate a road, it should also recognize the costs to users caused by these actions. Most travelers clearly do attach significant value to their travel time—otherwise traffic congestion would not generate so much public concern and irritation. In a national survey conducted in 2000, FHWA found that frustration with construction-related delay ranked among the top items of motorist dissatisfaction.² Finally, the value of travel time in delay is not arbitrary or uncertain. Economists are able to measure its value with a good degree of accuracy (see section on BCA for information on the valuation of travel time).

Even if user costs are not counted on a dollar-to-dollar basis with agency costs, quantifying them through LCCA informs decision makers about the “level of pain” to road users from any given project design alternative. It also provides an important perspective about the cost-effectiveness of strategies to reduce work zone disruptions (see box).

TOOLS

A wide variety of proprietary and nonproprietary tools are available with which to analyze the life-cycle costs of highway projects. These tools are usually spreadsheet-based applications, some of which incorporate risk analysis techniques.

² See “Moving Ahead: The American Public Speaks On Roadways And Transportation In Communities,” FHWA-OP-01-017, February 1, 2001, <http://www.fhwa.dot.gov/reports/movingahead.htm>.

THE IMPORTANCE OF KEEPING USER COSTS IN PERSPECTIVE

The following excerpt illustrates one reason why user costs should be evaluated along with agency costs for construction projects:

“When are they going to be done?” It’s a question echoed by frustrated motorists forced to navigate through large construction zones across the region. In fact, highway officials acknowledge, people who complain that road construction projects are taking longer and longer are right.

Traffic is slowing road repairs, they say. Highways that could be rebuilt quickly if shut down completely must remain open to prevent backups from growing even worse. Meanwhile, ever-lengthening rush hours have eaten into the time available to close even one lane. Road crews must proceed more cautiously when working amid traffic. (“Road Work Adds to Traffic and Vice Versa,” *Washington Post*, May 13, 2002, p. B1).

By placing dollar values on user costs, the costs of strategies to maintain traffic flow can be evaluated and compared. In some cases, life-cycle cost analysis may reveal it is less costly for agencies and users to do a temporary road closure than to stretch out construction.

FHWA has undertaken several initiatives to promote the application of LCCA in the highway pavement design process. “Life-Cycle Cost Analysis in Pavement Design,” an FHWA interim technical bulletin (FHWA-SA-98-079, 1998), is an important resource to LCCA practitioners. It provides guidance on the estimation and treatment of both agency and user costs in pavement design and maintenance. In 2002, FHWA released a primer on LCCA and a spreadsheet software program (RealCost) to do LCCA for pavement designs. The “Life-Cycle Cost Analysis Primer” (FHWA IF-02-047) is available on the Office of Asset Management Web site, <http://www.fhwa.dot.gov/infrastructure/asstmgmt/invest.htm>. The Web site also provides a link to the interim technical bulletin. FHWA offers a free workshop to highway agencies on the use of its RealCost LCCA software and the methodology underlying it.

BENEFIT-COST ANALYSIS

LCCA is a useful economic tool for selecting among alternatives where benefits of the possible project alternatives are essentially identical. In many cases, however, alternatives that an agency is considering may not generate identical benefits. For instance, when reconstructing a road, an agency may wish to consider reconstructing it as is or with additional lanes. The appropriate economic tool for these instances is benefit-cost analysis (BCA), which considers life-cycle benefits as well as life-cycle costs (see box).

BCA attempts to capture all benefits and costs accruing to society from a project or course of action, regardless of which particular party realizes the benefits or costs, or the form these benefits and costs take. Used properly, BCA reveals the economically efficient investment alternative, i.e., the one that maximizes the net benefits to the public from an allocation of resources.

BCA is not the same thing as financial analysis. Financial analysis is concerned with how to fund a project over its lifespan and measures the adequacy of current and future funds and revenues to cover the cost of building, operating, and maintaining the project. While financial analysis is an important part of project management, the economic merit of the project as measured by BCA is generally not affected by how the project is financed.

USEFUL APPLICATIONS OF BENEFIT-COST ANALYSIS

Benefit-cost analysis (BCA) considers the changes in benefits and costs that would be caused by a potential improvement to the status quo facility. In highway decision making, BCA may be used to help determine the following:

- Whether or not a project should be undertaken at all (i.e., whether the project's life-cycle benefits will exceed its costs).
- When a project should be undertaken. BCA may reveal that the project does not pass economic muster now, but would be worth pursuing 10 years from now due to projected regional traffic growth. If so, it would be prudent to take steps now to preserve the future project's right-of-way.
- Which among many competing alternatives and projects should be funded given a limited budget. BCA can be used to select from among design alternatives that yield different benefits (e.g., reconstruct a roadway with additional lanes versus no additional lanes); unrelated highway projects (a widened road versus an interchange on another road); and unrelated transportation projects in different transportation modes.

THE BENEFIT-COST ANALYSIS PROCESS

In BCA, the analyst applies a discount rate to the benefits and costs incurred in each year of the project's life cycle. This exercise yields one or more alternative measures of a project's economic merit.

The BCA process (see box) begins with the establishment of objectives for an improvement to a highway facility, such as reducing traffic congestion or improving safety. A clear statement of the objective(s) is essential to reduce the number of alternatives considered. The next step is to identify constraints (policy, legal, natural, or other) on potential agency options and specify assumptions about the future, such as expected regional traffic growth and vehicle mixes over the projected lifespan of the improvement.

Having identified objectives and assumptions, the analyst (or analytical team) then develops a full set of reasonable improvement alternatives to meet the objectives. This process begins with the development of a "do minimal" option, known as the base case. The base case represents the continued operation of the current facility under good management practices but without major investments.³ Under these "do minimal" conditions, the condition and performance of the base case would be

MAJOR STEPS IN THE BENEFIT-COST ANALYSIS PROCESS

1. Establish objectives
2. Identify constraints and specify assumptions
3. Define base case and identify alternatives
4. Set analysis period
5. Define level of effort for screening alternatives
6. Analyze traffic effects
7. Estimate benefits and costs relative to base case
8. Evaluate risk
9. Compare net benefits and rank alternatives
10. Make recommendations

³ The base case is sometimes called the "do nothing" option, but this term can be mistaken to mean that future management of the facility is not responsive to change. The term "do minimal" conveys the notion of ongoing managerial discretion to adjust to changing circumstances in the base case scenario.

expected to decline over time. Reasonable improvement alternatives to the base case can include a range of options, from major rehabilitation of the existing facility to full-depth reconstruction to replacement by a higher volume facility. Such alternatives will often involve construction, but alternatives that improve highway operations (such as the use of intelligent transportation systems) or manage travel demand (such as incentives for off-peak travel) are suitable for consideration.

To ensure that the alternatives can be compared fairly, the analyst specifies a multiyear analysis period over which the life-cycle costs and benefits of all alternatives will be measured. The analysis period is selected to be long enough to include at least one major rehabilitation activity for each alternative.

Ideally, the level of effort allocated to quantifying benefits and costs in the BCA is proportional to the expense, complexity, and controversy of the project. Also, to reduce effort, the alternatives are screened initially to ensure that the greatest share of analytical effort is allocated to the most promising ones. Detailed analysis of all alternatives is usually not necessary.

When an alternative is expected to generate significant net benefits to users, particularly in the form of congestion relief, the analyst evaluates the effect that the alternative would have on the future traffic levels and patterns projected for the base case (see section on Forecasting Traffic for Benefit Calculations, page 27). Changes in future traffic flows in response to an alternative will affect the calculation of project benefits and costs.

The investment costs, hours of delay, crash rates, and other effects of each alternative are measured using engineering methods and then compared to those of the base case, and the differences relative to the base case are quantified by year for each alternative. The analyst assigns dollar values to the different effects (e.g., the fewer hours of delay associated with an alternative relative to the base case are multiplied by a dollar value per hour) and discounts them to a present value amount. Risk associated with uncertain costs, traffic levels, and economic values also is assessed (see section on Risk Analysis, page 30).

Any alternative where the value of discounted benefits exceeds the value of discounted costs is worth pursuing from an economic standpoint. For any given project, however, only one design alternative can be selected. Usually, this alternative will be the economically efficient one, for which benefits exceed costs by the largest amount.

Based on the results of the BCA and associated risk analysis, the analyst prepares a recommendation concern-



ing the best alternative from an economic standpoint. It is good practice to document the recommendation with a summary of the analysis process conducted. In some cases, particularly for larger projects, this summary will include a discussion about the economic impact analysis conducted based on the results of the BCA (see section on Economic Impact Analysis, page 32).

BENEFIT AND COST ELEMENTS TO INCLUDE

Table 2 lists the benefit and cost categories and elements that are generally included in BCA.

The user elements in Table 2 are labeled as “cost/benefit” rather than “cost” or “benefit” only. This is because improvement alternatives are being compared to the base case (the “do minimal” option), and each may have a different impact on users. For instance, one alternative may reduce crash rates (a benefit) relative to the base case; another alternative may increase crash rates (a cost, also called a negative benefit or disbenefit) relative to the base case. In BCA, most, if not all, agency and user elements will vary relative to the base case—thus, contrary to LCCA, all elements must typically be considered and quantified.

TABLE 2. Benefits and Costs Typically Considered in Benefit-Cost Analysis

Agency Costs
Design and engineering
Land acquisition
Construction
Reconstruction/Rehabilitation
Preservation/Routine maintenance
Mitigation (e.g., noise barriers)
User Costs/Benefits Associated With Work Zones
Delay
Crashes
Vehicle operating costs
User Costs/Benefits Associated With Facility Operations
Travel time and delay
Crashes
Vehicle operating costs
Externalities (nonuser impacts, if applicable)
Emissions
Noise
Other impacts

Note that toll receipts and other user fees are not listed as benefits or costs in Table 2. Rather, they represent transfers of some of a project's benefits from users to the agency operating the project (see box).

Many people are puzzled about how economists assign monetary values to highway project benefits and costs. For instance, how does one value an hour of travel time, or a crash? The valuation of each of the major elements listed in Table 2 is described below.

Agency costs. The assignment of monetary values to the design and construction of a project is perhaps the easiest valuation concept to understand. Engineers estimate these costs based on past experience, bid prices, design specifications, materials costs, and other information. Care must be taken to make a complete capital cost estimation, including contingencies and administrative expenses such as internal staff planning and overhead costs.

A common error in economic analysis and budgeting is the underestimation of project construction and development costs. Particular care should be used when costing large or complicated projects.

Expenses associated with a project's financing, such as depreciation and interest payments, are not included in the BCA. The equivalent value of such expenses is already captured in the BCA through the application of the discount rate to the agency cost of the project. Adding depreciation or interest expense to agency costs in BCA would in most cases lead to double counting of costs.

Travel time and delay. An hour of travel associated with a business trip or commerce is usually valued at the average traveler's wage plus overhead—representing the cost to the traveler's employer. Personal travel time (either for commuting or leisure) is usually valued as a percentage of average personal wage and/or through estimates

TREATMENT OF REVENUES, TOLLS, TAXES, AND OTHER TRANSFERS IN BENEFIT COST ANALYSIS

Tolls, taxes, and other user charges for transportation projects constitute important potential revenue sources to State agencies for financing transportation projects. However, these revenue sources are not "benefits" of a project as measured by economic analysis such as benefit-cost analysis (BCA). Rather, these charges represent a means by which some of the benefits to users of the transportation project (as measured by their implicit willingness to pay for reduced travel time or improved safety) can be transferred in whole or in part (in the form of cash payments by the users) to the State or private agency that operates the facility. Adding toll or tax revenues to the value of travel time, safety, and vehicle operating cost benefits already included in the BCA would be double counting benefits.

Nonetheless, when significant tolls, taxes, and other user charges are proposed for a project, the BCA process should account for the effect of such charges on future use of the facility. In particular, the payment of a toll transfers the value of some of the time saving or other user benefit from the traveler to the facility operator, thereby reducing the value of ben-

efits realized by the traveler. Consequently, a traveler would typically use the facility less often if it were tolled than if it were not tolled, affecting future congestion and user benefits on the facility and surrounding roads. This response can be measured through an economic factor known as price elasticity of demand (see section on Forecasting Traffic, page 27).

Revenues from tolls and taxes are also of interest for an evaluation of a project's financial feasibility (as opposed to economic efficiency)—whether the improvement generates enough cash to pay for its own development and operation. This financial evaluation may be important to determine if the improvement can be implemented, particularly if conventional public transportation funding sources are inadequate. Similarly, it will help reveal if the project can be built and operated by a private sector vendor, or through a public-private partnership.

Finally, due to their impact on facility usage, tolls, taxes, and other user charges on existing facilities are potential policy alternatives to new construction that may be considered in their own right for reducing congestion on some facilities.

of what travelers would be willing to pay to reduce travel time. The U.S. Department of Transportation (USDOT) recommends that analysts value local personal travel time at 50 percent of average wage (see “Departmental Guidance for the Valuation of Travel Time in Economic Analysis,” available on the internet, for additional guidance). The value of reduced travel time often accounts for the greatest share of a transportation project’s benefits.

Crashes. The assignment of monetary values to changes in crash rates or severities can provoke controversy because crashes often involve injury or loss of life. The use of reasonable crash values is critical, however, to avoid underinvesting in highway safety. Economists often use the dollar amounts that travelers are willing to pay to reduce their risk of injury or death to estimate monetary values for fatalities and injuries associated with crashes. Medical, property, legal, and other crash-related costs are also calculated and added to these amounts. USDOT offers extensive guidance on this subject (see “Revision of Departmental Guidance on Treatment of the Value of Life and Injuries,” and “The Economic Impact of Motor Vehicle Crashes,” 2000 (DOT HS 809 446), available on the internet).

Vehicle operating costs. The costs of owning and operating vehicles can be affected by a project due to the changes that it causes in highway speeds, traffic congestion, pave-

ment surface, and other conditions that affect vehicle fuel consumption and wear and tear. Accurate calculations of a project’s effect on vehicle operating costs (VOC) require good information on the relationship of vehicle performance to highway conditions, and clear assumptions about future vehicle fleet fuel efficiency and performance. USDOT does not provide official guidance on estimating VOC, but useful information on the valuation of VOC (and other BCA elements) is provided in AASHTO’s 1977 “Manual on User Benefit Analysis of Highway and Bus-Transit Improvements” and its successor document, and in the “Highway Economic Requirements System Volume IV: Technical Report” (FHWA-PL-00-028), Chapter 7. Benefits attributable to lower VOC are usually not a major component of a project’s benefit stream.

Externalities. One of the more challenging areas of BCA is the treatment and valuation of the “externalities” of transportation projects. In economics, an externality is the uncompensated impact of one person’s actions on the well-being of a bystander (see box). In the case of transportation investments, “bystanders” are the nonusers of the project. When the impact benefits the nonuser, this is called a positive externality. When the impact is adverse, this is called a negative externality.

Often, when there is talk about externalities of highways, the focus is on negative externalities. Negative externalities include undesirable effects of a project on air

EXTERNALITIES VERSUS INDIRECT EFFECTS

Externalities considered in benefit-cost analysis (BCA) are the uncompensated *direct* impacts of the project on nonusers of the project. These effects are additive to other direct costs and benefits (such as the value of time saving or reduced crashes and saved lives) measured in the BCA. Direct effects, however, usually lead to indirect effects on the regional economy through the actions of the marketplace. Indirect impacts of a transportation project could include local changes in employment or land use. The value of indirect effects is usually *not* additional to that of direct effects measured in BCA; rather, indirect effects are a restatement or transfer to other parties of the value of direct effects. Indirect economic effects are measured using economic impact analysis and not BCA (see section on Economic Impact Analysis, page 32).

and water quality, noise and construction disruptions, and various community and aesthetic impacts. Positive externalities, however, also exist. A project may serve to reduce air or noise pollution from levels that would have otherwise prevailed without it.

Several methods exist for including externalities in BCA. In some cases, scientific and economic studies have revealed per-unit costs for air pollutants, for example, that can be incorporated directly into the BCA. Much uncertainty surrounds these valuations, however. Values can vary from project to project due to location, climate, and pre-existing environmental conditions. Risk analysis techniques (see section on Risk Analysis, page 30) can yield helpful information about the sensitivity of results to these uncertain values.

Externalities are specifically dealt with in environmental assessments required by the National Environmental Policy Act (NEPA). Where adverse impacts are identified, mitigation is required to avoid, minimize, or compensate for them. Required mitigation is part of the environmental decision, and the costs of mitigation will become “internalized” in the project’s cost in the BCA. The BCA effort should be coordinated closely with the NEPA assessment (see box).

When an externality cannot be put into dollar terms, it can often be dealt with on a qualitative basis relative to other, monetized components of the BCA. If the measurable net benefits of a project are highly positive, the presence of minor unquantified externalities can be tolerated from an economic standpoint even if they are perceived to be negative. On the other hand, if the net benefits are very low, then the existence of significant unquantified negative externalities may tip the economic balance against the project.

ECONOMIC ANALYSIS AND THE NATIONAL ENVIRONMENTAL POLICY ACT PROCESS

Any State or local project or activity receiving Federal funds or other Federal approvals must undergo analysis of a comprehensive set of its social, economic, and environmental impacts under the provisions of the National Environmental Policy Act of 1969 (NEPA). The findings of the NEPA analysis have a major influence on the selection of a particular project or project alternative.

When an environmental impact statement (EIS) is prepared under NEPA and economic, social, natural, or physical environmental effects are interrelated, then the EIS must discuss all of these effects on the human environment. If a benefit-cost analysis (BCA) is prepared to assist in project selection, it should be incorporated by reference or appended to the EIS as an aid in evaluating the environmental consequences. This information will complement other information assembled in the EIS. However, for purposes of complying with NEPA, the merits and drawbacks of the various alternatives need not be displayed in a monetary BCA, and typically are not.

Accordingly, information revealed in a BCA can inform the NEPA process. Similarly, information on the direct costs or benefits of environmental impacts of a project measured in the NEPA review can be incorporated into the economic analysis.

COMPARING BENEFITS TO COSTS

Once the analyst has calculated all benefits and costs of the project alternatives and discounted them, there are several measures to compare benefits to costs in BCA. The two most widely used measures are described below.

- *Net present value (NPV)*. NPV is perhaps the most straightforward BCA measure. All benefits and costs over an alternative's life cycle are discounted to the present, and the costs are subtracted from the benefits to yield a NPV. If benefits exceed costs, the NPV is positive and the project is worth pursuing. Where two or more alternatives for a project exist, the one with the highest NPV over an equivalent analysis period should usually be pursued. Policy issues, perceived risk, and funding availability, however, may lead to the selection of an alternative with a lower, positive NPV.
- *Benefit-cost ratio (BCR)*: The BCR is frequently used to select among projects when funding restrictions apply. In this measure, the present value of benefits (including negative

benefits) is placed in the numerator of the ratio and the present value of the initial agency investment cost is placed in the denominator. The ratio is usually expressed as a quotient (e.g., \$2.2 million/\$1.1 million = 2.0). For any given budget, the projects with the highest BCRs can be selected to form a package of projects that yields the greatest multiple of benefits to costs (see box, page 24).

FHWA recommends the use of either the NPV or BCR measures for most economic evaluations. Other BCA measures are available and may be used, however, depending on agency preference. For example, the equivalent uniform annual value approach converts the NPV measure into an annuity amount. The internal rate of return measure represents the discount rate necessary to yield an NPV of zero from a project's multiyear benefit and cost stream.



APPROPRIATE USE OF THE BENEFIT-COST RATIO

The benefit-cost ratio (BCR) is often used to select among competing projects when an agency is operating under budget constraints. In particular, use of the BCR can identify a collection of projects that yields the greatest multiple of benefits to costs, where the ability to incur costs is limited by available funds. However, care must be taken when relying on the BCR as the primary benefit-cost analysis (BCA) measure.

The Federal Highway Administration (FHWA) recommends that only the initial agency investment cost be included in the denominator of the ratio. All other BCA values, including periodic rehabilitation costs or user costs, such as delay associated with construction, should be included in the ratio's numerator as positive or negative benefits. Adherence to this guidance facilitates consistent project comparisons. For instance, assume there are two potential projects, each with a present value of \$1 million in initial investment costs, \$4 million in user benefits, and \$1 million in negative benefits associated with user delay at construction work zones. If the analyst includes the negative benefits with the benefits in the numerator of the BCR, the BCR would be $(\$4 \text{ million} - \$1 \text{ million})/\$1 \text{ million}$, or 3, for both projects. On the other hand, if the analyst includes the negative benefits with the initial investment costs in the denominator of the BCR, the BCR would be $\$4 \text{ million}/(\$1 \text{ million} + \$1 \text{ million})$, or 2, for both projects. If the analyst were inconsistent and assigned the respective negative benefits to the numerator of one project and the denominator of the other, then the first project would appear superior based on the BCR (3 versus 2), when in fact, each project would yield the same net present value of \$2 million ($\$4 \text{ million} - \$1 \text{ million} - \1 million).

It is also good practice not to base a selection from among two or more alternatives solely on simple BCR values, without reference to the budget or other investment opportunities. Consider the case of two alternatives to improve an intersection. One alternative (improved traffic signals with left-turn lanes) has modest benefits to the public (\$10 million in present value) but a low initial investment cost (\$500,000)—yielding a BCR of 20. The other alternative (constructing a grade-separated intersection) has high benefits (\$100 million in present value) but an initial investment cost of \$10 million—yielding a lower BCR (10) than the first alternative. Selection of the first alternative, based solely on its higher BCR, would preclude (at least for some period of time) the opportunity for the traveling public to gain the much higher net benefits associated with the second alternative. In fact, selection of the first alternative would only be appropriate if enough other projects existed with BCRs above 10 such that the collective benefits of the first alternative plus these other projects funded with the \$10 million needed for the second alternative would equal or exceed the \$100 million in benefits of the second alternative.

Use of specialized procedures such as incremental BCA, in which the increments in benefits and costs of one alternative relative to another are compared in ratio format and prioritized subject to budget constraints, can minimize the risk of selecting inferior alternatives using BCRs. A good description of the incremental BCA approach is provided in chapter 7 of “HERS-ST 2.0 Highway Economic Requirements System—State Version Overview,” FHWA, September 2002, <http://isddc.dot.gov/OLPFiles/FHWA/010617.pdf>.

MISUNDERSTANDINGS

BCA is a powerful, informative tool available to assist planners, engineers, and decision makers. Agencies often avoid or underutilize BCA due to misconceptions about it.

In some cases, agency personnel are skeptical about the accuracy of BCA due to perceived uncertainties in measuring or valuing costs and benefits. In reality, there is much more substance to economic analysis techniques and values than is generally understood. Where uncertainty does exist, it can usually be measured and managed. It is helpful to remember that sound economic analysis reduces uncertainty. Not doing the analysis only serves to hide uncertainty from decision makers.

Another concern is that the workload involved in BCA may be excessive relative to agency resources. Once the engineering and economic capabilities are in place, however, BCA workloads diminish markedly. BCA level of effort should also reflect project cost, complexity, and controversy—routine projects may be analyzed with minimal effort.

Finally, some agencies are concerned that the results of BCA could conflict with preferred or mandated outcomes. In any situation, an objective and independent assessment of a project's economic consequences can contribute valuable information to the decision process. There are, however, valid reasons why decision makers may choose to override or constrain economic information. For example, if there are concerns that BCA results would disproportionately favor projects in urban areas, policy makers can initially apportion funds between urban and rural areas based on equity considerations. Urban projects would then compete based on their economic merits for the urban funds; rural projects would similarly compete for the rural funds.

AVOIDING PITFALLS

As with any analytic method, BCA can give erroneous results if it is misused. Perhaps the foremost cause of error in BCA is the selection of an unrealistic base case. The base case must be premised on intelligent use and management of the asset during the analysis period. For instance, allowances should be made for traffic diversion and changing peak periods as congestion builds in the base case (the broader importance of accurate traffic forecasts is discussed in the next section, page 27). Failure to do this can lead to overly pessimistic estimates of delay levels in the base case, to which by comparison any alternative would look attractive. BCA results can also be biased by the comparison of only one design alternative to the base case, even though less costly alternatives exist. Proper BCA considers a full range of reasonable alternatives.

Another common BCA problem involves the evaluation of a “project” that is actually a combination of two or more independent or separable projects. In such cases, the net benefits of one project may hide the net costs of the other, or vice versa. Both of the projects would either be built or rejected if incorrectly joined together, when in fact one should be built and the other rejected.

BCA results can be erroneous if they do not include the correct cost or benefit elements or amounts associated with a project. This problem happens most often with the omission of user costs or major externalities (if present). In some cases, an agency may focus only on local costs and benefits, failing to include those that accrue outside its jurisdiction. Care must also be taken not to include “benefits” that are simply restatements of other benefits (or costs) measured elsewhere in the BCA. This latter error, a form of double counting, can occur when employment, business, or land use effects measured using economic impact analysis are added to the travel time saving, safety, and vehicle operating cost benefits of a project. A more thorough discussion of this latter issue is provided later in this primer, in the section on Economic Impact Analysis (page 32).

TOOLS

Many tools that can accommodate BCA are available. The majority of tools capture benefits and costs at the project level only, but some tools can estimate the net benefits of projects at the program level.

In the United States, perhaps the best-known BCA tool for highways is that presented in the 1977 AASHTO “Manual on User Benefit Analysis of Highway and Bus-Transit Improvements,” referred to as the 1977 Redbook. This guide is being updated under a National Cooperative Highway Research Program contract and will be re-issued. The Texas Transportation Institute developed the MicroBENCOST model to implement the guidance in the 1977 Redbook. A few States have developed their own BCA models.

Some software applications are specific to subsets of highway investments. For instance, the Federal Railroad

Administration’s Gradedec software is specific to the BCA evaluation of upgrades, separations, and closures of highway-rail grade crossings.

In 2000, FHWA released a State-level version of its Highway Economic Requirements System (HERS-ST). HERS-ST is a computer model that applies BCA to section-level highway data to predict system-wide investment requirements. HERS-ST considers capital improvements directed at correcting pavement, geometric, or capacity deficiencies. HERS-ST can determine the program funding levels required to achieve desired highway performance goals in a cost-beneficial way. Alternatively, the model can estimate the highway system performance that would result from various program-funding levels. An abundance of material concerning HERS-ST is available on the Office of Asset Management Web site, <http://www.fhwa.dot.gov/infrastructure/asstmgmt/invest.htm>.

FORECASTING TRAFFIC FOR BENEFIT CALCULATIONS

Traffic volumes determine both the number of travelers who will benefit from a highway improvement project and, in the case of capacity enhancement projects, the future congestion relief provided by the project. Accordingly, accurate forecasts of traffic volumes are critical to obtaining valid results from BCA.

Traffic forecasting is often more complicated than it first appears. An assumption that the historic growth rate of traffic on a road will continue unchanged after it is improved can lead to significant miscalculations of its actual future traffic. In fact, traffic levels on an improved road may increase faster than anticipated as drivers seek to take advantage of its better driving conditions.



TRAFFIC FLOWS ARE DYNAMIC

Why would a road attract more traffic volume after it is improved than it would if it were not improved?

Drivers who formerly avoided the facility because it was too congested may start to use it once the congestion has been reduced by an improvement. Many of these drivers will divert to the improved facility from other congested regional roads. Similarly, some drivers who formerly traveled in off-peak hours on the facility to avoid severe congestion will shift back to peak hours, adding to peak hour volumes when congestion is most noticeable to commuters.

Other drivers will “unchain” existing trips into multiple trips or make new trips that they might otherwise have avoided due to excessive delay associated with congestion. Some individuals may shift from transit to automobile. Drivers may also make longer trips (to more remote locations) than they did before the improvement. Other traffic responses can and do occur.

The new and diverted users of the improved facility will enjoy benefits, just as will the existing users. These additional users, however, will use up some of the capacity of the improved facility, reducing the congestion relief that would have resulted for existing users had the additional users not arrived.

TRAFFIC FORECASTING PROCESS

The traffic forecasting process begins with the collection of data on current traffic on the facility and throughout the region, followed by the calculation of expected growth in traffic for the region in general. This base case regional traffic projection should reflect expected economic, demographic, and land use trends, based on historic and projected relationships between these factors and regional traffic growth.

Data on expected regional traffic growth can then be entered into the region's travel demand model to simulate regional traffic flows with and without the new highway capacity. MPOs and States typically maintain the travel demand models for planning purposes. Most travel demand models now in use are effective at measuring the extent to which existing network traffic will divert to new capacity—a major source of “new” traffic on improved roads. Other traffic responses can be approximated even when they are not measured explicitly by the models. For instance, the models can be manipulated, through various feedback adjustments, to simulate the effects of mode shifts and alternative destinations chosen by regional travelers in response to a reduction in congestion. Although not explicitly captured in most travel demand models, the shifting of traffic to and from peak periods as congestion levels change can be estimated using supplemental methods.

NETWORK AND CORRIDOR EFFECTS

A travel demand model may indicate that a significant amount of future traffic on the facility to be improved will be diverted from other roads in the region. This effect, while mitigating some of the congestion relief on the improved facility itself, will reduce congestion on the other roads. In this case, the BCA for the new capacity project should attempt to incorporate the beneficial effects (as measured by the travel demand model) of the improved facility on other roads in the corridor as well as on the facility itself. Of course, reduced delay on the affected roads may lead to some compensating, new trip generation on those roads as well.

IMPACT ON BENEFIT CALCULATIONS

Unless the analyst considers traffic responses to an improved facility, he or she may overestimate the benefits of the improved facility to existing users and understate the benefits to the new users and those drivers on other roads in the regional highway network. This can lead to misperceptions by decision makers and members of the public about the important benefits of new capacity on regional traffic patterns and congestion.

On the improved facility, the time saving benefit per trip for pre-existing users will diminish relative to what it would have been had traffic volume not changed, but will

still be positive. This saving can be calculated directly from the reduction in delay based on changes in the volume/capacity ratios caused by the improvement, after allowing for traffic adjustments. Users of other routes in the network who do not divert to the improved facility will similarly receive time saving benefits caused by the reduction in traffic volume due to the diversion of others to the improved facility.

Users on the improved facility who diverted from other routes will receive benefits equal, on average, to the midpoint between those of pre-existing users of the improved facility and those of users of other facilities who do not divert from those facilities. This midpoint value reflects the fact that some diverted users will gain the full time saving of the improved facility but others will do only slightly better than had they not diverted. By a similar computation, users making new (as opposed to diverted) trips on the improved facility or other routes can be shown to experience benefits equal, on average, to half of those experienced by pre-existing users on the respective facilities.

Numbers of affected users for each user class, along with data on the amount of time saving, can be derived from the travel demand modeling procedures described in this section.

WHEN TO DO A FULL DEMAND FORECAST

Standard travel demand modeling, principally addressing trip diversion, is often sufficient for BCA of routine capacity projects. State or MPO planning offices often undertake such modeling as a matter of course in their preparation of transportation improvement plans. In general, it is a good idea to conduct BCA in close coordination with planning offices.

A comprehensive traffic forecast, incorporating the full range of traffic responses to capacity improvements, should be done for regionally significant or controversial projects. It is easy for the credibility of the BCA to be challenged if it is learned that new trips or other effects of new capacity were ignored. Traffic forecasting can be used to educate the public that the new capacity leads to benefits for more than just the existing users of the to-be-improved road, and that traffic diverting to the new road will reduce congestion throughout the network.

PRICE ELASTICITY OF DEMAND AND TRAFFIC FORECASTING

An important benefit of a capacity expansion project is the reduction in travel times for highway users. Travel time is a major component in overall price or cost to the user, which includes time as well as out-of-pocket costs. As with most goods and services, a lower price can be expected to lead to more quantity demanded—in this case, some additional travel.

Price elasticity of demand is an economic concept used to summarize how much more or less of something people will consume if its price changes. From the standpoint of estimating future traffic levels, elasticity represents how a change in the cost of driving, due to a reduction in travel time or implementation of a toll, may affect the volume of travel that will take place. These changes in volume result from some drivers' decisions to make more or fewer trips than they otherwise would have made.

Elasticity is stated in percentage change terms, e.g., an X percent reduction in travel price leads to a Y percent increase in travel miles or trips. An elasticity of zero implies that travel is unresponsive to a price

change, no matter how large, while an infinite elasticity implies that even a one-second decrease in travel time will cause all capacity to be completely absorbed.

While price elasticity is a generally accepted tool in economics, there are differing opinions about how to apply it in a transportation context. The transportation economics literature reveals a wide range of measured elasticity values, reflecting different study methods, data, time periods, and locations. No studies, however, suggest that travel demand elasticity is either zero or infinite. When measured on a given facility, observed elasticity includes the effects of both diverted trips, which represent existing traffic that has simply shifted from other routes or time periods, and new travel taken as a consequence of the lower user cost. Additional research is needed to narrow the range of elasticity values that are applicable to a given set of circumstances—whether facility, corridor, or region—and to develop methods for better incorporating demand elasticity into traffic forecasting.

RISK ANALYSIS

Uncertainty is a factor in the analysis of transportation projects just as it is in any other enterprise. Fortunately, much of the uncertainty associated with transportation investments can be evaluated and managed.

DEFINING RISK

Typically, the analyst is faced with a number of uncertainties when evaluating a highway investment. Many of these uncertainties can be measured by quantifying the probability of an event and its impact if it occurs. Measured uncertainty is known as “risk.” Risk can be identified and understood by answering three questions:

- *What can happen?* The following are examples of things that can happen that would change BCA results: there are initial construction or future rehabilitation cost overruns, facility service life is less or more than expected, or traffic volumes vary significantly from projections.
- *How likely is it to happen?* Some things are more likely to occur than are others. For instance, it may be that the project in question is well understood and unlikely to have construction cost overruns.
- *What are the consequences of an event occurring?* In some cases, an input variable may be subject to significant variability, but any given occurrence (within a realistic range) would not substantially affect the economic justification for the project. For instance, the price of a paving material may be subject to large swings, but the benefits of a particular alternative using that material may be sufficiently large to maintain the alternative as the preferred one even if the paving material price doubles. In other cases, there may be little likelihood that an event will occur (such as an earthquake), but its occurrence would have major consequences unless certain precautions are taken in the project’s design.

Risk analysis will help the analyst answer these questions and determine if efforts to mitigate some or all of the risk would be cost-effective.

SENSITIVITY ANALYSIS

The traditional means by which analysts have evaluated risk is through sensitivity analysis. In a typical sensitivity analysis, the value of an input variable identified as a significant potential source of uncertainty is changed (either within some percentage of the initial value or over a range of reasonable values) while all other input values are held constant, and the amount of change in analysis results is noted. This sensitivity process is repeated for other input variables for which risk has been identified. The input variables may then be ranked according to the effect of their variability on BCA results.

Sensitivity analysis allows the analyst to get a feel for the impact of the variability of individual inputs on overall economic results. In general, if the sensitivity analysis reveals that reasonable changes in an uncertain input variable will not change the relative economic ranking of project alternatives or undermine the project’s economic justification, then the analyst can have reasonable comfort that the results are robust. Alternatively, a reasonable change in an uncertain input value could severely undermine the project’s economic justification. If so, the analyst would investigate methods to reduce the risk of a change in that input value and analyze steps to minimize consequences if the adverse event occurs. If the risk cannot be mitigated, the analyst may recommend against undertaking that particular project design.

PROBABILISTIC ANALYSIS

There is usually some uncertainty associated with several variables in an economic analysis, and these variables may vary simultaneously. Sensitivity analysis as traditionally practiced can measure the effect of a change in more than one variable at a time, but the results of analysis involving many different scenarios can become confusing to interpret. Fortunately, continuing advances in computing power available through microcomputers permit the practice of probabilistic-based risk analysis, most often through a method known as Monte Carlo simulation.

In Monte Carlo simulation, the analyst assigns an appropriate probability distribution (based on expert opinion, historical data, and other information) to each of the input variables subject to uncertainty in the economic analysis. The Monte Carlo simulation samples randomly from the probability distributions for each input, runs the selected input values through the BCA formula to calculate a discrete economic result, and then repeats this process over and over again. The results, which are based on the randomly selected input values, are arrayed in the form of an average BCA result and a probability distribution covering all potential outcomes of the BCA.

Figure 2 illustrates the NPV outcomes of two competing project alternatives analyzed using the Monte Carlo simulation method. This particular analysis is relatively easy to interpret. Assume that these are two alternatives to accomplish a particular project, or two projects competing for the same funding. Alternative B has a

higher mean NPV (represented by the value under the peak) than does alternative A. The NPV for alternative A, however, has a tighter range of potential values than does alternative B, and, unlike alternative B, is not at significant risk of having a negative NPV. If the decision maker were risk neutral (or a risk taker), alternative B would be preferred. If the decision maker were risk averse, alternative A, with its somewhat lower NPV but lower range of downside outcomes, might be preferred.

MITIGATING RISK

Once risks have been identified and quantified, the next step is to evaluate potential actions to mitigate them. Many actions may be taken to reduce risk, including increased engineering, additional quality testing, application of value engineering, and various contractual methods such as design/build. In some cases, the object of risk mitigation may be to shift risk to the party that is most able to control it, such as through the use of construction warranties.

The reduction of risk to the agency and the traveling public associated with a potential risk mitigation action must be weighed against the cost of the action. Accordingly, the range of potential economic outcomes for the project should be calculated with and without the risk mitigation action in place. If a highway agency were risk neutral, it would pursue risk mitigation to the extent that the cost of the action(s) is at least compensated by the higher expected value of the mean BCA outcome (e.g., due to a reduction in the number of potential downside NPV outcomes). If the agency is risk averse, it may decide to accept a lower expected NPV in exchange for reduced downside risk.

More information on risk analysis, particularly as applied in LCCA, is available in “Life-Cycle Cost Analysis in Pavement Design,” an FHWA interim technical bulletin (FHWA-SA-98-079, 1998). This document is available on the Office of Asset Management Web site at <http://www.fhwa.dot.gov/infrastructure/asstmgmt/lcca.htm>.

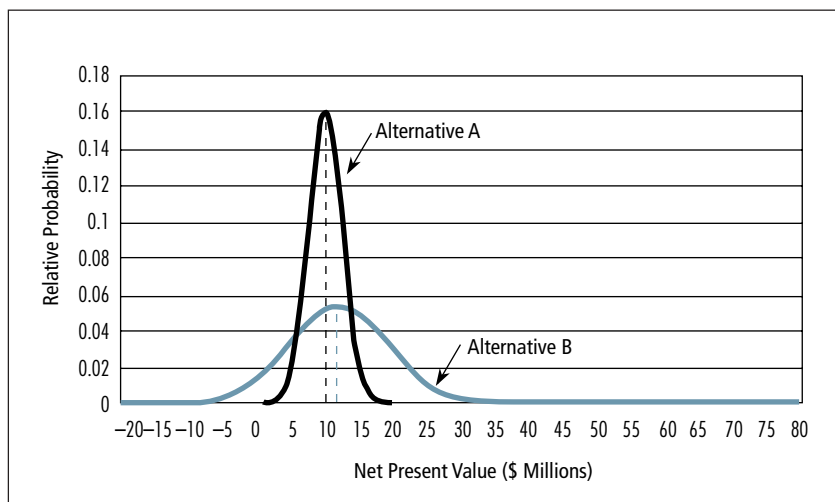


FIGURE 2. Probabilistic Outcome Distributions

ECONOMIC IMPACT ANALYSIS

Economic impact analysis (EIA) is the study of the way in which the direct benefits and costs of a highway project (such as travel time saving) affect the local, regional, or national economy. It attempts to measure the consequences that a highway project or action will have on considerations such as local or regional employment patterns, wage levels, business activity, tourism, housing, and even migration patterns. As used in this primer, EIA should not be confused with Environmental Impact Analysis as related to requirements of the National Environmental Policy Act of 1969 and other environmental laws, regulations, and guidance.



ROLE OF ECONOMIC IMPACT ANALYSIS

BCA measures the direct benefits and costs that a project causes for highway agencies, travelers (users), and, in the case of externalities, to nonusers affected by the project. Direct benefits and costs are the first order or immediate impacts of the transportation project on users and nonusers, and consist of elements described earlier in this primer, including changes in travel time, crashes, vehicle operating costs, agency construction costs, and pollution costs. BCA typically does not measure how these direct benefits and costs are converted into indirect effects on the economy, such as changes in employment, wages, business sales, or land use. This is the role of EIA.

Economists generally hold that the direct benefits and costs of transportation improvements measured using BCA are converted into wider, indirect, economic impacts through the operation of the marketplace. These converted, indirect effects are assumed to have the same net monetary value as the BCA-measured direct effects. Significantly, the value of most converted economic effects is not additive to the value of the BCA-measured direct effects—rather, the former value is a restatement or capitalization of the latter value.

For instance, faster commuting times may induce more people to purchase houses distant from an employment center. This new demand for more remote properties drives up the price of the remote properties. Thus, the highway user transfers part of the value of his or her travel time saving to the owners of the remote properties in the

form of a higher purchase price than he or she would have paid had the highway improvement not been built.

WHEN TO DO ECONOMIC IMPACT ANALYSIS

In many instances, the findings of BCA are compelling in their own right. A project intended to improve safety or reduce traffic congestion can often be justified in light of the number and value of crashes avoided or hours of traveler time saved. Even so, indirect economic impacts measured by EIA based on BCA results are of major interest to decision makers, planners, and the public, especially for large projects that are expected to generate major direct transportation benefits and costs.

Similarly, individuals are generally at least as concerned about the specific effects of a project on themselves as they are about its overall effect on the public. People who would particularly benefit may advocate for the project; those who perceive that they would be worse off may raise strong objections to the project. EIA can identify who these people are likely to be and how they would be affected. If EIA shows that those who are better off from the project greatly outnumber those who are worse off, it is easier to build public support for the project.

Any State or local project or activity receiving Federal funds or other Federal approvals must undergo analysis of a comprehensive set of its social, economic, and environmental impacts under the provisions of NEPA. EIA can play an important role in supporting this analysis.

METHODS AND TOOLS

There are many different levels of sophistication in EIA. As with BCA, the best method and level of effort for any given project depends on the scale, complexity, and controversy of the project.⁴

Basic methods of EIA include survey studies, market studies, and comparable case studies. Surveys may take the form of expert interviews (e.g., with businesses along a route), vehicle origin-destination logs, collection of shopper origin-destination data, and corridor inventory (windshield survey) methods. Survey studies are generally qualitative interpretations of the effects of transpor-

⁴The categories and descriptions in this section on EIA methods are based on NCHRP Synthesis Report 290, "Current Practices for Assessing Economic Development Impacts from Transportation Investments: A Synthesis of Highway Practice," 2000.



tation projects, preferably informed by BCA and other economic data pertaining to the transportation effects of highway projects.

Market studies consider demand and supply for business activity and then attempt to quantify the effects on the market of a change in transportation costs caused by a project. Comparable case studies are most often used to evaluate the localized economic impacts of a project on neighborhoods, downtowns, or small towns. This approach is applied to projects such as bypasses of small towns, where comparable projects and situations elsewhere in the same State or region can be readily identified and studied.

More advanced EIA methods encompass econometric analysis and economic modeling, including productivity impact analysis and regional economic models. Productivity impact analysis, also known as the production function approach, attempts to measure aggregate economic growth that may result from additional highway spending. This approach seeks to capture productivity benefits not typically included in BCA.

Input-output analysis is a key component of most regional economic modeling of the employment, output, and income impacts of transportation infrastructure investments. Input-output analysis quantifies the multiple economic effects resulting from a change in the final demand for a specific product or service. For example, a person being paid to work on a highway project will spend some of those wages to buy goods and services. The money he or she spends shows up as sales and wages to other parties, who spend the money elsewhere, and so on. This chain of effects, known as the “multiplier,” captures the distributive effects of transportation capital spending and operating benefits across a broad range of industries. Typically, the input-output multipliers are driven by the initial, direct benefits and costs of the project measured by BCA.

The simplest regional economic models are direct applications of input-output models, such as RIMS II (“Regional Input-Output Modeling System,” 2nd edition, U.S. Department of Commerce). These applications are “static” in the sense that they provide an all-at-once view of economic effects, without a time component that is necessary for understanding when the effects will be realized. More sophisticated applications of regional economic models supplement input-output relationships with

simulation techniques to forecast the year-to-year effects of projects on economic and demographic patterns. The most complex EIA models are those that integrate travel demand models, land use models, dynamic simulation economic models, and input-output models.

PRESENTATION OF RESULTS

As a matter of best practice, EIA results should be presented as a complementary analysis to the BCA. BCA results show whether a project is worth the resources that will be invested in it from a total social welfare standpoint. EIA results are helpful in informing decision makers and the public about how and in what form the benefits and costs of the project will ultimately be distributed within the economy. Information from both analyses may be summarized in a recommendations package and considered jointly in reaching a decision on whether or not to go forward with a project. The EIA results should neither state nor imply, however, that the monetary value of indirect economic effects is additional to the NPV measured in the BCA. To do so would overstate the economic justification of the project by effectively double counting the project’s net benefits.

CONCLUSION

The goal of this primer has been to describe the major principles, concepts, and methods for doing economic analysis of highway projects. The coverage of these subjects has been necessarily brief. For the interested reader, a wealth of additional information is available from publicly accessible sources.⁵ The material in this primer, however, will hopefully be sufficient to provide a learning framework, and to make the reader aware of several key points.

First and foremost, economic analysis provides valuable information to the planning, design, construction, preservation, and operation of the transportation infrastructure. The limited supply of transportation dollars must be invested in a manner that gives the greatest return to the public. The most objective way to accomplish this is to compare the benefits and costs of transportation projects through the standard unit of the discounted dollar over the life cycles of projects. As such, economic analysis is an integral component of any comprehensive infrastructure management methodology, such as Transportation Asset Management.

Benefit-cost analysis is the most comprehensive method to evaluate the reasonableness of highway projects in economic terms. In some cases, when it is clear that a project must be undertaken regardless of its cost (e.g., a critical bridge on an interstate highway must be repaired or replaced in kind), LCCA will reveal the most cost-effective way of accomplishing the project. Used properly and in coordination with other disciplines, these methods can accommodate everything from user delay associated with work zones to measuring the net benefits of new roadway capacity.

State agencies and other practitioners typically must invest some effort to establish the skills and procedures needed to conduct economic analysis. Once established, however, economic analysis integrates with existing planning, environmental, and engineering practices with minimal additional work. In fact, by directly addressing issues such as the effect of new highway capacity on traffic patterns or the justification for a project, economic analysis can considerably lessen agency workloads associated with designing projects to appropriate scale and demonstrating the need for such projects to the public.

Uncertainty is a complicating factor in economic analysis as it is in virtually every area of human endeavor. Uncertainty can be measured and quantified as risk through risk analysis methods. Using economic analysis to evaluate the net benefits of various risk reduction strategies can help agencies manage risk.

Finally, through the mechanism of the marketplace, the direct benefits and costs of highway projects will cause various indirect effects on local and regional economies, including impacts on employment levels, wages, business activity, and housing prices. EIA tools can measure these indirect effects of highway projects based on the findings of BCA. Indirect effects are often of major interest to decision makers and the public, and, particularly for large projects, can be presented in a complementary analysis to the BCA.

⁵For instance, the FHWA Office of Asset Management Web site, <http://www.fhwa.dot.gov/infrastructure/asstmgmt/index.htm>, has links to many references for each of the subjects discussed in this primer.

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