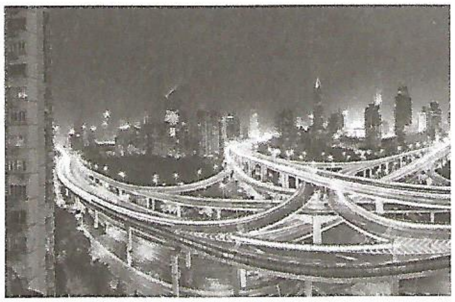
CHAPTER 13



Evaluating Transportation Alternatives

In the previous chapter, methods and techniques were described for establishing the demand for transportation services under a given set of conditions. The results of this process furnish the necessary input data to prepare an evaluation of the relative worth of alternative projects. This chapter describes how transportation project evaluations are conducted and compared based on quantitative information.

CHAPTER OBJECTIVES:

- Understand the basic questions and issues to consider prior to beginning an evaluation analysis.
- Calculate net benefits to road users based on supply-demand relationships.
- Determine project cost including initial investment, vehicle operating, travel time, and accidents.
- Apply the equations used in economic evaluation methods.
- Learn how to use evaluation methods based on multiple criteria.

13.1 BASIC ISSUES IN EVALUATION

The basic concept of an evaluation is simple and straightforward, but the actual process itself can be complex and involved. A transportation project is usually proposed because of a perceived problem or need. For example, a project to improve safety at a railroad grade crossing may be based on citizen complaints about accidents or time delays at the crossing site. In most instances, there are many ways to solve the problem, and each solution or alternative will result in a unique outcome in terms of project cost and results. In the railroad grade crossing example, one solution would be to install gates and flashing lights; another solution would be to construct a grade-separated overpass. These two solutions are quite different in terms of their costs and effectiveness. The first solution will be less costly than the second, but it also will be less effective in reducing accidents and delays.

A transportation improvement can be viewed as a mechanism for producing a result desired by society at a price. The question is, will the benefits of the project be worth the cost? In some instances, the results may be confined to the users of the system (as in the case of the grade crossing), whereas in other instances, those affected may include persons in the community who do not use the system.

Prior to beginning an analysis to evaluate a transportation alternative, the engineer or planner should consider a number of basic questions and issues. These will assist in determining the proper approach to be taken, what data are needed, and what analytical techniques should be used. These issues are discussed in the following sections.

13.1.1 Objectives of Evaluation

What information is needed for project selection? The objective of an evaluation is to furnish the appropriate information about the outcome of each alternative so that a selection can be made. The evaluation process should be viewed as an activity in which information relevant to the selection is available to the person or group who will make a decision. An essential input in the process is to know what information will be important in making a project selection. In some instances, a single criterion may be paramount (such as cost); in other cases, there may be many objectives to be achieved. The decision maker may wish to have the relative outcome of each alternative expressed as a single number, whereas at other times, it may be more helpful to see the results individually for each criteria and each alternative.

There are many methods and approaches for preparing a transportation project evaluation, and each one can be useful when correctly applied. This chapter describes the considerations in selecting an evaluation method and discusses issues that are raised in the evaluation process. Two classes of evaluation methods are considered that are based on a single measure of effectiveness: The first reduces all outcomes to a monetary value, and the second reduces all outcomes to a numerical relative value. Evaluation can also be viewed as a fact-finding process in which all outcomes are reported separately in a matrix format that provides the decision maker with complete information about the project outcome. This information can be used in public forums for citizen input, and the decision process can be extended to include public participation.

Evaluations also can be made after a project is completed to determine if the outcomes for the project are as had been anticipated. *Post facto* evaluation can be very helpful in formulating information useful for evaluating similar projects elsewhere or in making modifications in original designs. Thus, *post facto* evaluations are described and illustrated using the results of evaluations for completed projects.

13.1.2 Identifying Project Stakeholders

Who will use the information, and what are their viewpoints? A transportation project can affect a variety of groups in different ways. In some instances, only one or a few groups are involved; in other cases, many factions have an interest. Examples of groups that could be affected by a transportation project include the system users; transportation management; labor; citizens in the community; businesses; and local, state, and national governments. Each of these groups may have special concerns. Since these viewpoints may differ from group to group, the elements of the evaluation process itself will be reflective of the viewpoints expressed.

For smaller, self-contained projects, those groups with something to gain or lose by the project—the *stakeholders*—usually will be limited to the system users and transportation management. For larger, regional-scale transportation projects, the number and variety of stakeholders will increase because the project will affect many groups in addition to the users and management. For example, a major project could increase business in the downtown area, or expanded construction activity could trigger an economic boom in the area. The project might also require the taking of land, or it could create other environmental effects. Thus, if the viewpoint is that of an individual traveler or business, the analysis can be made on narrow economic grounds. If the viewpoint is that of the community at large, then the analysis must consider a wider spectrum of concerns.

If the viewpoint were that of a local community, then the transfer of funds by grants from the state or federal government would not be considered to be a cost, whereas increases in land values within the area would be considered a benefit. However, if the viewpoint were expanded to a regional or state level, these grants and land-value increases would be viewed as costs to the region or as transfers of benefits from one area to another. Thus, a clear definition of whose viewpoint is being considered in the evaluation is necessary if proper consideration is to be given to how these groups are either positively or negatively affected by each proposed alternative.

13.1.3 Selecting and Measuring Evaluation Criteria

What are the relevant criteria, and how should these be measured? A transportation project is intended to accomplish one or more goals and objectives, which are made operational as criteria. The numerical or relative results for each criterion are called *measures of effectiveness.* For example, in a railroad grade crossing problem, if the goal is to reduce accidents, the criteria can be measured as the number of accidents expected to occur for each of the alternatives considered. If another goal is to reduce waiting time, the criteria could be the number of minutes per vehicle delayed at the grade crossing. Nonquantifiable criteria also can be used and expressed in a relative scale, such as high, medium, and low.

Criteria selection is a basic element of the evaluation process because the measure used becomes the basis on which each project is compared. Thus, it is important that the criteria be related as closely as possible to the stated objective. To use a nontransportation example for illustration, if the objective of a university course is to learn traffic and highway engineering, then a relevant criterion to measure results is exam grades, whereas a less relevant criterion is the number of class lectures attended. Both are measures of class performance, but the first is more relevant in measuring how well the stated objective was achieved.

Criteria not only must be relevant to the problem but should also have other attributes. They should be easy to measure and sensitive to changes made in each alternative. Also, it is advisable to limit the number of criteria to those that will be most helpful in reaching a decision in order to keep the analysis manageable for both the engineer who is doing the work and the person(s) who will act on the result. Too much information can be confusing and counterproductive and, rather than being helpful, could create uncertainty and encourage a decision on a political or other nonquantitative basis. Some examples of criteria used in transportation evaluation are listed in Table 13.1.

13.1.4 Measures of Effectiveness

How are measures of effectiveness used in the evaluation process itself? One approach is to convert each measure of effectiveness to a common unit and then, for each alternative, compute the summation for all measures. A common unit is money, and it may be

Table 13.1 Criteria for Evaluating Transportation Alternatives

- Capital costs
  - —Construction
  - —Right-of-way
  - —Vehicles
- Maintenance costs
- Facility operating costs
- Travel time
  - —Total hours and cost of system travel
  - —Average door-to-door speed
  - —Distribution of door-to-door speeds
- Vehicle operating costs
- Safety
- Social and environmental costs
  - —Noise
  - —Visual quality
  - —Community cohesion
  - —Air and water quality

possible to make a transformation of the relevant criteria to equivalent dollars and then compare each alternative from an economic point of view. For example, if the cost of an accident is known and the value of travel time can be determined, then for the railroad grade crossing problem, it would be possible to compute a single number that would represent the total cost involved for each alternative, since construction, maintenance, and operating costs are already known in dollar terms, and the accident and time costs can be computed using conversion rates.

A second approach is to convert each measure of effectiveness to a numerical score. For example, if a project alternative does well in one criterion, it is given a high score; if it does poorly in another criterion, it is given a low score. A single number can be calculated that represents the weighted average score of all the measures of effectiveness that were considered. This approach is similar to calculating grades in a course. The instructor establishes both a set of criteria to measure a student's performance (for example, homework, midterms, finals, class attendance, and a term paper) and weights for each criterion. The overall measure of the student's performance is the weighted sum of the outcome for each measure of effectiveness. Measures of effectiveness should be independent of each other if a summation procedure (such as adding grades) is to be used in the evaluation. If the criteria are correlated, then totaling the weighted scores will bias the outcome. (This would suggest, for example, that homework grades should not be included in a student's final grade since they may correlate with midterm results.)

A third way is to identify the measures of effectiveness for each alternative in a matrix form, with no attempt made to combine them. This approach furnishes the maximum amount of information without prejudging either how the measures of effectiveness should be combined or their relative importance.

13.1.5 Evaluation Procedures and Decision Making

How well will the evaluation process assist in making a decision? The decision maker typically needs to know what the costs of the project will be; in many instances, this alone will determine the outcome. Another question may be, do the benefits justify the expenditure of funds for transportation, or would the money be better spent elsewhere? The decision maker also will want to know if the proposed project is likely to produce the stated results—that is, how confident can we be of the predicted outcomes?

It may be necessary to carry out a sensitivity analysis that shows a range of values rather than a single number. Also, evaluations of similar projects elsewhere may provide clues to the probable success of the proposed venture. The decision maker also may wish to know if all the alternatives have been considered and how they compare with the one being recommended. Are there other ways to accomplish the objective, such as using management and traffic-control strategies that would eliminate the need for a costly construction project? It may be that providing separate bus and carpool lanes results in significant increases in the passenger-carrying capacity of a freeway, thus eliminating the need to build additional highway lanes.

The decision maker may want to know the cost to highway users as the result of travel delays during construction. Also of interest may be the length of time necessary to finish the project, since public officials are often interested in seeing work completed during their administration. The source of funds for the project and other matters dealing with its implementation will also be of concern. Thus, in addition to the fairly straightforward problem of evaluation based on a selected set of measurable criteria, the transportation engineer must also be prepared to answer any and all questions about the project and its implications.

The evaluation process requires that the engineer have all appropriate facts about a proposed project and be able to convey these in a clear and logical manner to facilitate decision making. In addition to the formal numerical summaries of each project, the engineer also must be prepared to answer other questions about the project that relate to its political and financial feasibility. In the final analysis, the selection itself will be based on a variety of factors and considerations that reflect all the inputs that a decision maker receives from the appropriate source.

13.2 EVALUATION BASED ON ECONOMIC CRITERIA

To begin the discussion of economic evaluation, it is helpful to consider the relationship between the supply and demand for transportation services. Consider a particular transportation project, such as a section of roadway or a bridge. Further, assume that we can calculate the cost involved for a motorist to travel on the facility. (These costs would include fuel, tolls, travel time, maintenance, and other actual or perceived out-of-pocket expenses.) Using methods described in Chapter 12, we can calculate the traffic volumes (or demand) for various values of user cost. As explained in Chapter 2, as the cost of using the facility decreases, the number of vehicles per day will increase. This relationship is shown schematically in Figure 13.1, which represents the demand curve for the facility for a particular group of motorists.

A demand curve can shift upward or downward and have a different slope for users with different incomes or for various trip purposes. If the curve moves upward, it indicates a greater willingness to pay, reflecting perhaps a group with a higher income. If the slope approaches horizontal, it indicates that demand is elastic (i.e., that a small change in price results in a large change in volume). If the slope approaches vertical, it indicates that the demand is inelastic (i.e., that a large change in price has little effect on demand). As an example, the price of gasoline is said to be inelastic because people seem to drive equally as often after gas prices increase as before the increase.

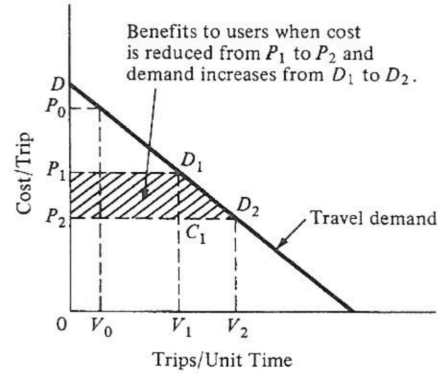


Figure 13.1 Demand Curve for Travel on a Given Facility

Consider the cost to travel on this facility to be P_1. The number of trips per unit time will be V_1 and the total cost for all users over a given period per hour or day will be $(P_1) \times (V_1)$. This amount can be shown graphically as the area of rectangle $0P_1D_1V_1$. As can be seen from the demand curve, all but the last user would have been willing to pay more than the actual price. For example, V_0 users would have been willing to pay P_0 to use the facility whereas they paid the lesser amount P_1. The area under the demand curve $0DD_1V_1$ is the amount that the V_1 users would be willing to pay. If we subtract the area $0P_1D_1V_1$, which is the amount the users actually paid, we are left with the area P_1DD_1. This triangular area is referred to as a *consumer surplus* and represents the value of the economic benefit for the current users of the facility.

Suppose the price for using the facility is reduced to P_2 because of various improvements that have been made to the facility. The total user cost is now equal to $(P_2) \times (V_2)$, and the consumer surplus is the triangular area between the demand curve and P_2D_2 or P_2DD_2. The net benefit of the project is the net increase in consumer surplus or area P_2DD_2 minus area P_1DD_1 and is represented by the shaded trapezoidal area $P_2P_1D_1D_2$. That area is made up of two parts: The first is the reduction in total cost paid by the original travelers, V_1, and is represented by the rectangular area $P_2P_1D_1C_1$. The second is the consumer surplus earned by the new users $V_2 - V_1$ and is represented by the triangular area $C_1D_1D_2$.

Thus, a theoretical basis has been established to calculate the net benefits to users of an improved transportation facility which then can be compared with the improvement cost. For a linear demand curve, the formula for user benefits is

$$B_{2,1} = \frac{1}{2}(P_1 - P_2)(V_1 + V_2) \qquad (13.1)$$

where

$B_{2,1}$ = net benefits to transport users
P_1 = user cost of unimproved facility
P_2 = user cost of improved facility
V_1 = volume of travel on unimproved facility
V_2 = volume of travel on improved facility

It is not practical to develop demand curves, but rather the four-step process described in Chapter 12 is used. In these instances, the value for the volume that is used in economic calculations is taken to be the number of trips that will occur on the improved facility. Equation 13.2, which replaces the term $\frac{1}{2}(V_1 + V_2)$ of Eq. 13.1 with V_2, has been commonly used in highway engineering studies. This formula will overstate benefits unless demand is inelastic; that is, if the demand curve is vertical (i.e., $V_1 = V_2$).

$$B_{2,1} = (P_1 - P_2)(V_2) \tag{13.2}$$

To consider the economic worth of improving this transportation facility, calculate the cost of the improvement and compare it with the cost of maintaining the facility in its present condition (the do-nothing alternative). One approach is to consider the difference in costs, to compare this with the difference in benefits, and then to select the project if the net increase in benefits exceeds the net increase in costs. Another approach is to consider the total costs of each alternative, including user and facility costs, and then to select the project that has the lowest total cost. Thus, to carry out an economic evaluation, it is necessary to develop the elements of cost for both the facility and the users. These include facility costs for construction, maintenance, and operation and user costs for travel time, accidents, and vehicle operations. The elements of cost are discussed in the following section.

13.2.1 Elements of Cost

The cost of a transportation facility improvement includes two components: *first cost* and *continuing costs.* Since an evaluation is concerned with cost differences, those costs that are common to both projects can be excluded. The first cost for a highway or transit project may include engineering design, right-of-way, and construction. Each transportation project is unique, and the specifics of the design will dictate what items will be required and at what cost. Continuing costs include maintenance, operation, and administration. These are recurring costs that will be incurred over the life of the facility and are usually based on historical data for similar projects. For example, if one alternative involves the purchase of buses, then the first (or capital) cost is the price of the bus, and the operating and maintenance cost will be known from manufacturer data or experience.

Expenses for administration or other overhead charges are usually excluded in an economic evaluation, because they will be incurred regardless of whether or not the project is selected. Other excluded costs are those that already have been incurred. These are known as *sunk costs* and as such are not relevant to the decision of what to do in the future since these expenditures have already been made. For most capital projects, a service life must be determined and a salvage value estimated. *Salvage value* is the worth of an asset at the end of its service life. For example, a transit bus costing $150,000 may be considered to have a service life of 12 years and a salvage value of $20,000, and a concrete pavement may have a service life of 15 years and no salvage value. Suggested service lives for various facilities can be obtained from various transportation organizations, such as the American Association of State Highway and Transportation Officials (AASHTO) and the American Public Transportation Association (APTA).

As illustrated in Figure 13.2, three measures of user costs are typically included in a transportation project evaluation: motor vehicle operation, travel time, and traffic accidents. These costs may be referred to as *benefits,* the implication being that the improvements to a transportation facility will reduce the cost for the users—that is, lower the perceived price, as shown on the demand curve—and result in a user benefit. It is more appropriate to consider these in terms of their actual cost, because this format is used in economic evaluations.

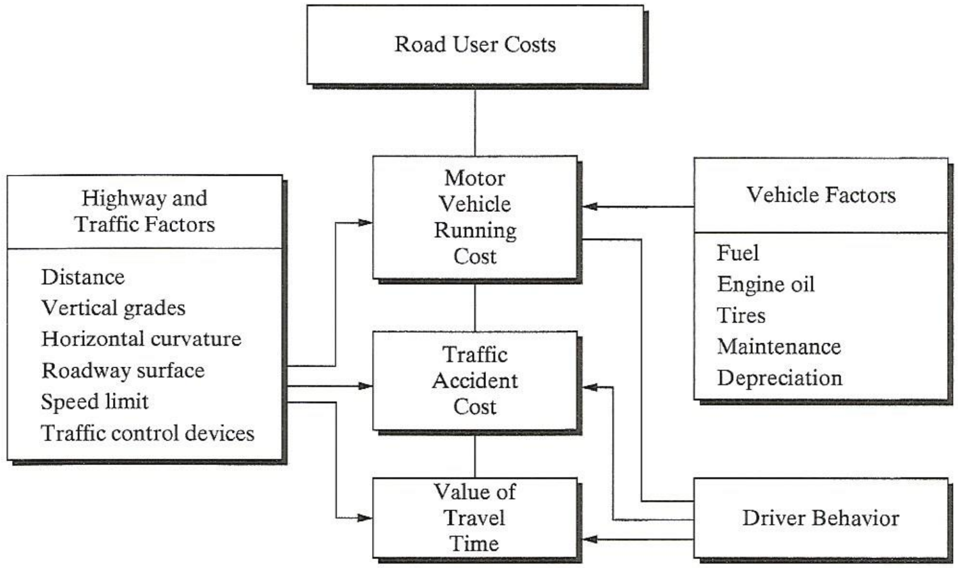


Figure 13.2 Road User Cost Factors

SOURCE: *Highway Engineering Economy,* U.S. Department of Transportation, Federal Highway Administration, April 1983

Vehicle Operating Costs

User costs for motor-vehicle operation are significant items in a highway project evaluation. For example, a road improvement that eliminates grades, curves, and traffic signals (as well as shortening the route) can result in major cost reductions to the motorist. Agencies, such as the U.S. Department of Transportation, The American Association of State and Highway Officials, and various vehicle manufacturers, furnish data useful in cost analysis for highways or at intersections.

Travel Time Costs

One of the most important reasons for making transportation improvements is to increase speed or to reduce travel delay. In the world of trade and commerce, time is equivalent to money. For example, business ventures that furnish overnight delivery of small packages have grown and flourished. Transoceanic airline service replaced steamships because airplanes reduced the time to cross the ocean from 6 to 9 days to 6 to 9 hours. The tunnel between Great Britain and France (known as the Chunnel), which opened in 1994, has shortened trip time by replacing ferries with rail.

The method of handling travel time in an economic analysis has stirred considerable debate. There is general agreement that time savings have an economic value, but the question is whether these can and should be converted to dollar amounts. One problem is that a typical stream of traffic contains both private and commercial vehicles, each of which values time quite differently. The value of time for a trucking firm can be translated directly into labor cost savings by using an hourly rate for labor and equipment. Personal travel, on the other hand, is made for a variety of reasons; some are work related, but many are not (shopping, school, social, recreation). Time saved in traveling to and from work can be related to wages earned, but time saved in other pursuits may have little, if any, economic basis for conversion.

The value of time saved also depends on the length of trip and family income. If time saved is small—less than 5 min—it will not be perceived as significant and will therefore have little value. If time saved is above a threshold level where it will make a noticeable difference in total travel time—over 15 min—then it could have significant economic value. The apparent monetary savings from even small travel time reductions can be quite large. For example, if a highway project that will carry average daily traffic (ADT) of 50,000 autos saves only 2 min per traveler, and the value of time for the average motorist is estimated conservatively at \$5.00/hour, the total minimum annual savings is $50{,}000 \times (2/60) \times 365 \times 5 = \$3{,}041{,}667$. At 10 percent interest, these savings could justify spending a total of almost \$26 million for a 20-year project life. Clearly, this result is an exaggeration of the actual benefits received. Although travel time does represent an economic benefit, the conversion to a dollar value is always open to question. AASHTO has used the average value approach. Others would argue that time savings should be credited only for commercial uses or stated simply in terms of actual value of number of hours saved.

The Federal Highway Administration (FHWA) has published a method for estimating the benefits of highway improvements known as the Highway Economic Requirements System (HERS). Travel time costs are computed using the following equation.

$$TTCST_{vt} = \frac{1000}{AES_{vt}}(TTVAL_{vt}) \tag{13.3}$$

where

$TTCST_{vt}$ = average travel time cost for vehicles of type vt
AES_{vt} = average effective speed of vehicle type vt (mi/h)
$TTVAL_{vt}$ = average value of one hour of travel time for occupants and cargo in vehicle type vt (\$/h) in the year 2000 (see Table 13.2)

The value of one hour of travel time, expressed in year 2011 dollars (\$), is shown in Table 13.2 for seven classes of vehicles (two auto and five truck types). The values for hourly time cost have been adjusted using an inflation factor based on the cost index. The first row of figures is for business-only travel. The second row of figures is a weighted average of business and nonbusiness travel. For example, for the small auto, 10 percent of trips are for business (\$41.52/hr), and 90 percent of trips are for other purposes (\$18.95/hr), such that the weighted average is approximately 0.10(\$41.52) + 0.90(\$18.95) = \$21.22. Because six-tire trucks and larger vehicles are primarily used for business travel, corresponding hourly values for other purposes are not provided in Table 13.2.

Table 13.2 Value of One Hour of Travel Time for Various Vehicle Types (Year 2011 \$)

Trip Purpose	*Small Auto*	*Medium Auto*	*4-Tire Truck*	*6-Tire Truck*	*3- or 4-Axle Truck*	*4-Axle Combo*	*5-Axle Combo*
Business only	\$41.52	\$41.96	\$29.95	\$37.02	\$40.07	\$46.00	\$46.83
Other purposes	\$18.95	\$18.95	\$18.95	—	—	—	—
All purposes	\$21.22	\$21.26	\$22.37	\$37.02	\$40.07	\$46.00	\$46.83

SOURCE: Based on data from NCHRP Report 456, *Guidebook for Assessing the Social and Economic Effects of Transportation Projects*, Transportation Research Board, National Research Council, Washington, D.C., 2001

Crash or Accident Costs

Loss of life, injury, and property damage incurred in a transportation crash or accident is a continuing national concern. Following every major air tragedy is an extensive investigation; and following the investigation, expenditures of funds are often authorized to improve the nation's air navigation system. Similarly, the 55-mi/h highway speed limit imposed by Congress following the oil crisis of 1973 to 1974 was retained long after the crisis ended because it was credited with saving lives on the nation's highways. In 1995, Congress removed all federal restrictions on speed limits.

It has been well established that the crash rate per million vehicle-miles traveled is substantially lower on limited-access highways than on four-lane undivided roads. Reflecting the economic costs of crashes requires both an estimate of the number and type that are likely to occur over the life of the facility and an estimate of the value of each occurrence. Property damage and injury-related crashes can be valued using insurance data. The value of a human life is "priceless," but in economic terms, measures such as future earnings have been used. There is no simple numerical answer to the question: What is the value of a human life lost in a highway crash? There is general agreement that economic value does exist and published data vary widely. The most prudent approach, if an economic value is desired, is to select a value that appears most appropriate for the given situation.

13.2.2 Economic Evaluation Methods

An economic evaluation of a transportation project is completed using one of the following methods: present worth (PW), equivalent uniform annual cost (EUAC), benefit–cost ratio (BCR), or internal rate of return (ROR). Each method, when correctly used as shown in Example 13.1, will produce the same results. The reason for selecting one over the others is preference for how the results will be presented. Since transportation projects are usually built to serve traffic over a long period of time, it is necessary to consider the time-dependent value of money over the life of a project.

Present Worth

The most straightforward of the economic evaluation methods is the present worth (PW), since it represents the current value of all the costs that will be incurred over the lifetime of the project. The general expression for present worth of a project is

$$PW = \sum_{n=0}^{N} \frac{C_n}{(1+i)^n} \qquad (13.4)$$

where

C_n = facility and user costs incurred in year n
N = service life of the facility (in years)
i = interest rate

Net Present Worth

The present worth of a given cash flow that has both receipts and disbursements is referred to as the net present worth (NPW).

The use of an interest rate in an economic evaluation is common practice because it represents the cost of capital. Money spent on a transportation project is no longer available for other investments. Therefore, a minimal value of interest rate is the rate that would have been earned if the money were invested elsewhere. For example, if \$1000 were deposited in a bank at 8 percent interest, its value in five years would be $1000(1 + 0.08)^5$ = \$1469.33. Thus, the PW of having \$1469.33 in five years at 8 percent interest is equivalent to \$1000, and the opportunity cost is 8 percent. Discount rates can be higher or lower, depending on risk of investment and economic conditions.

It is helpful to use a cash flow diagram to depict the costs and revenues that will occur over the lifetime of a project. Time is plotted as the horizontal axis and money as the vertical axis, as illustrated in Figure 13.3. Using Eq. 13.5, we can calculate the NPW of the project, which is

$$\text{NPW} = \sum_{n=0}^{N} \frac{R_n}{(1+i)^n} + \frac{S}{(1+i)^n} - \sum_{n=0}^{N} \frac{M_n + O_n + U_n}{(1+i)^n} - C_o \tag{13.5}$$

where

C_o = initial construction cost

n = a specific year

M_n = maintenance cost in year n

O_n = operating cost in year n

U_n = user cost in year n

S = salvage value

R_n = revenues in year n

N = service life, years

In this manner, a time stream of costs and revenues is converted into a single number: the NPW. The term $1/(1 + i)^n$ is known as the present worth factor of a single payment and is written as $P/F - i - N$, or $P/F_{i,N}$, where P is the present value given the future amount F, and N is the years of service life.

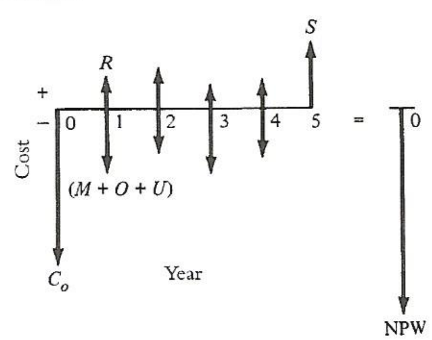


Figure 13.3 Typical Cash Flow Diagram for a Transportation Alternative and Equivalence as Net Present Worth

Equivalent Uniform Annual Worth

The conversion of a given cash flow to a series of equal annual amounts is referred to as the equivalent uniform annual worth (EUAW). If the uniform amounts are considered to occur at the end of the interest period, then the formula is

$$\text{EUAW} = \text{NPW}\left[\frac{i(1+i)^N}{(1+i)^N - 1}\right] = \text{NPW}(A/P - i - N) \tag{13.6}$$

Similarly,

$$\text{NPW} = \text{EUAW}\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right] = \text{EUAW}(P/A - i - N) \tag{13.7}$$

where

EUAW = equivalent uniform annual worth
NPW = net present worth
i = interest rate, expressed as a decimal
N = number of years

The term in the brackets in Eq. 13.6 is referred to as the capital recovery factor and represents the amount necessary to repay \$1 if N equal payments are made at interest rate i. For example, if a loan of \$5000 is to be repaid in equal monthly payments over a five-year period at 1 percent/month, then the amount is

$$\text{EUAW} = 5000\left[\frac{0.01(1+0.01)^{60}}{(1+0.01)^{60} - 1}\right] = 5000(0.02225) = 111.25$$

Thus, 60 payments of \$111.25 would repay a \$5000 debt, including both principal and interest. The NPW of a cash flow is converted to an EUAW by multiplying the NPW by the capital recovery factor.

The inverse of the capital recovery factor is the present worth factor for a uniform series, as stated in Eq. 13.7. Thus, the present value of 60 payments of \$111.25, at 1 percent per month, is

$$\text{NPW} = 111.25\left[\frac{(1+0.01)^{60} - 1}{0.01(1+0.01)^{60}}\right] = 111.25(44.96) = 5000$$

Solutions for values of i and N that convert a monetary value from a future to a present time period ($P/F - i - N$) and from a present time period to equal end-of-period payments ($A/P - i - N$) are tabulated in textbooks on engineering economics. Table 13.3 lists values of single-payment present worth factors (P/F) and capital recovery factors (A/P) for a selected range of interest rates and time periods.

Benefit–Cost Ratio

The ratio of the present worth of net project benefits and net project costs is called the benefit–cost ratio (BCR). This method is used in situations where it is desired to show

Table 13.3 Present Worth and Capital Recovery Factors

	i = 3		*i* = 5		*i* = 10		*i* = 15	
N	*(P/F)*	*(A/P)*	*(P/F)*	*(A/P)*	*(P/F)*	*(A/P)*	*(P/F)*	*(A/P)*
1	0.9709	1.0300	0.9524	1.0500	0.9091	1.1000	0.8696	1.1500
2	0.9426	0.5226	0.9070	0.5378	0.8264	0.5762	0.7561	0.6151
3	0.9151	0.3535	0.8638	0.3672	0.7513	0.4021	0.6575	0.4380
4	0.8885	0.2690	0.8227	0.2820	0.6830	0.3155	0.5718	0.3503
5	0.8626	0.2184	0.7835	0.2310	0.6209	0.2638	0.4972	0.2983
10	0.7441	0.1172	0.6139	0.1295	0.3855	0.1627	0.2472	0.1993
15	0.6419	0.0838	0.4810	0.0963	0.2394	0.1315	0.1229	0.1710
20	0.5537	0.0672	0.3769	0.0802	0.1486	0.1175	0.0611	0.1598
25	0.4776	0.0574	0.2953	0.0710	0.0923	0.1102	0.0304	0.1547
30	0.4120	0.0510	0.2314	0.0651	0.0573	0.1061	0.0151	0.1523
35	0.3554	0.0465	0.1813	0.0611	0.0356	0.1037	0.0075	0.1511
40	0.3066	0.0433	0.1420	0.0583	0.0221	0.1023	0.0037	0.1506
45	0.2644	0.0408	0.1113	0.0563	0.0137	0.1014	0.0019	0.1503
50	0.2281	0.0389	0.0872	0.0548	0.0085	0.1009	0.0009	0.1501

the extent to which an investment in a transportation project will result in a benefit to the investor. To do this, it is necessary to make project comparisons to determine how the added investment compares with the added benefits. The formula for BCR is

$$\text{BCR}_{2/1} = \frac{B_{2/1}}{C_{2/1}} \tag{13.8}$$

where

$B_{2/1}$ = reduction in user and operation costs between higher-cost Alternative 2 and lower-cost Alternative 1, expressed as PW or EUAW
$C_{2/1}$ = increase in facility costs, expressed as PW or EUAW

If the BCR is 1 or greater, then the higher cost alternative is economically attractive. If the BCR is less than 1, this alternative is discarded.

Correct application of the BCR method requires that costs for each alternative be converted to PW or EUAW values. The proposals must be ranked in ascending order of capital cost, including the do-nothing alternative, which usually has little, if any, initial cost. The incremental BCR is calculated for pairs of projects, beginning with the lowest cost alternative. If the higher-cost alternative yields a BCR less than 1, it is eliminated and the next-higher-cost alternative is compared with the lower cost alternative. If the higher-cost alternative yields a BCR equal to or greater than 1, it is retained and the lower-cost alternative is eliminated. This process continues until every alternative has been compared. The alternative selected is the one with the highest initial cost and a BCR of 1 or more with respect to lower-cost alternatives and a BCR less than 1 when compared with all higher-cost projects.

Internal Rate of Return

Rate of return (ROR) is the interest rate at which the PW of reductions in user and operation costs $B_{2/1}$ equals the PW of increases in facility costs $C_{2/1}$. If the ROR exceeds the interest rate (referred to as minimum attractive rate of return), the higher-cost project is retained. If the ROR is less than the interest rate, the higher priced project is eliminated. The procedure is similar to that used in the BCR method.

Example 13.1 Illustration of Economic Analysis Methods

The Department of Traffic is considering three improvement plans for a heavily traveled intersection within the city. The intersection improvement is expected to achieve three goals: improve travel speeds, increase safety, and reduce operating expenses for motorists. The annual dollar value of savings compared with existing conditions for each criterion as well as additional construction and maintenance costs is shown in Table 13.4. If the economic life of the road is considered to be 50 years and the discount rate is 3 percent, which alternative should be selected? Solve the problem using the four methods for economic analysis.

Solution:

- Compute the NPW of each project.

$$(P/A-3-50)=\frac{(1+i)^N-1}{i(1+i)^N}=\frac{(1+0.03)^{50}-1}{0.03(1+0.03)^{50}}=25.729$$

$$\begin{aligned}\text{NPW}_{\text{I}} &= -185{,}000+(-1500+5000+3000+500)(P/A-3-50)\\ &= -185{,}000+(7000)(25.729) = -185{,}000+180{,}103\\ &= -4897\end{aligned}$$

$$\begin{aligned}\text{NPW}_{\text{II}} &= -220{,}000+(-2500+5000+6500+500)(P/A-3-50)\\ &= -220{,}000+(9500)(25.729) = -220{,}000+244{,}425\\ &= +24{,}465\end{aligned}$$

$$\begin{aligned}\text{NPW}_{\text{III}} &= -310{,}000+(-3000+7000+6000+2800)(P/A-3-50)\\ &= -310{,}000+(12{,}800)(25{,}729) = -310{,}000+329{,}331\\ &= +19{,}331\end{aligned}$$

Table 13.4 Cost and Benefits for Improvement Plans with Respect to Existing Conditions

Alternative	*Construction Cost*	*Annual Savings in Accidents*	*Annual Travel Time Benefits*	*Annual Operating Savings*	*Annual Additional Maintenance Cost*
I	$185,000	$5000	$3000	$ 500	$1500
II	220,000	5000	6500	500	2500
III	310,000	7000	6000	2800	3000

The project with the highest NPW is alternative II.

- Solve by the EUAW method. Note $(A/P - 3 - 50) = 1/25.729 = 0.03887$.

$$\begin{aligned}
\text{EUAW}_{\text{I}} &= -185{,}000(A/P - 3 - 50) - 1500 + 5000 + 3000 + 500 \\
&= -185{,}000(0.03887) + 7000 = -7190 + 7000 \\
&= -190 \\
\text{EUAW}_{\text{II}} &= -220{,}000(A/P - 3 - 50) - 2500 + 5000 + 6500 + 500 \\
&= -220{,}000(0.03887) + 9500 = 8551 + 9500 \\
&= +949 \\
\text{EUAW}_{\text{III}} &= -310{,}000(0.03887) - 3000 + 7000 + 6000 + 2800 \\
&= -12{,}050 + 12{,}800 \\
&= +750
\end{aligned}$$

The project with the highest EUAW is Alternative II, which is as expected since EUAW = NPW(0.03887).

- Solve by the BCR method.

Step 1. Compare the BCR of Alternative I with respect to do-nothing (DN).

$$\text{BCR}_{\text{I/DN}} = \frac{180{,}103}{185{,}000} = 0.97$$

Since $\text{BCR}_{\text{I/DN}}$ is less than 1, we would not build Alternative I.

Step 2. Compare BCR of Alternative II with respect to DN.

$$\text{BCR}_{\text{II/DN}} = \frac{244{,}425}{220{,}000} = 1.11$$

Since BCR > 1, we would select Alternative II over DN.

Step 3. Compare BCR of Alternative III with respect to Alternative II.

$$\text{BCR} = \frac{(329{,}331) - (244{,}425)}{(310{,}000) - (220{,}000)} = \frac{84{,}906}{90{,}000} = 0.94$$

Since BCR is less than 1, we would not select Alternative III. We reach the same conclusion as previously, which is to select Alternative II.

- Solve by the ROR method. In this situation, we solve for the value of interest rate for which NPW = 0.

Step 1. Compute ROR for Alternative I versus DN. (Recall that all values are with respect to existing conditions.)

$$\text{NPW} = 0 = -185{,}000 + (-1500 + 5000 + 3000 + 500) \times (P/A - i - 50)$$

$$(P/A - i - 50) = 185{,}000/7000$$

$$(P/A - i - 50) = 26.428$$

$$i = 2.6\%$$

Since the ROR is lower than 3 percent, we discard Alternative I.

Step 2. Compute ROR for Alternative II versus DN.

$$NPW = 0 = -220{,}000 + (-2500 + 5000 + 6500 + 500) \times (P/A - i - 50)$$

$$(P/A - i - 50) = 220{,}000/9500$$

$$(P/A - i - 50) = 23.16$$

$$i = 3.6\%$$

Since ROR is greater than 3 percent, we select Alternative II over DN.

Step 3. Compute ROR for Alternative III versus Alternative II.

$$NPW = 0 = -(310{,}000 - 220{,}000) + (12{,}800 - 9500) \times (P/A - i - 50)$$

$$(P/A - i - 50) = 90{,}000/3300$$

$$(P/A - i - 50) = 27.27$$

$$i = 2.7\%$$

Since the increased investment in Alternative III yields an ROR less than 3 percent, we do not select it but again pick Alternative II.

The preceding example illustrates the basic procedures used in an economic evaluation. Four separate methods were used, each producing the same result. The PW or EUAW method is simplest to understand and apply and is recommended for most purposes when the economic lives of each alternative are equal. The BCR gives less information to the decision maker and must be carefully applied if it is to produce the correct answer. (For example, the alternative with the highest BCR with respect to the do-nothing case is not necessarily the best.) The ROR method requires more calculations but does provide additional information. For example, the highest ROR in the preceding problem was 3.6 percent. This says that if the minimum attractive ROR were greater than 3.6 percent (say 5 percent), none of the projects would be economically attractive.

13.3 EVALUATION BASED ON MULTIPLE CRITERIA

Many problems associated with economic methods limit their usefulness. Among these are

- Converting criteria values directly into dollar amounts
- Choosing the appropriate value of interest rate and service life
- Distinguishing between those groups that benefit from a project and those that pay
- Considering all costs, including external costs

For these reasons, economic evaluation methods should be used primarily for narrowly focused projects or as only one of many inputs for the evaluation of larger projects. The next section discusses evaluation methods that seek to include measurable criteria that are not translated just in monetary terms.

13.3.1 Rating and Ranking

Numerical scores are helpful in comparing the relative worth of alternatives in cases where criteria values cannot be transformed into monetary amounts. The basic equation is as follows.

$$S_i = \sum_{j=1}^{N} K_j V_{ij} \tag{13.9}$$

where

S_i = total value of score of alternative i
K_j = weight placed on criterion j
V_{ij} = relative value achieved by criteria j for alternative i

The application of this method is illustrated by the following example.

Example 13.2 Evaluating Light Rail Transit Alternatives Using the Rating and Ranking Method

A transportation agency is considering the construction of a light rail transit line from the center of town to a growing suburban region. The transit agency wishes to examine five alternative alignments, each of which has advantages and disadvantages in terms of cost, ridership, and service provided. The alternatives differ in length of the line, location, types of vehicles used, seating arrangements, operating speeds, and number of stops. The agency wants to evaluate each alternative using a ranking process. Determine which project should be selected.

Solution:

Step 1. Identify the goals and objectives of the project. The transit agency has determined that the new transit line should achieve five major objectives.

1. Net revenue generated by fares should be as large as possible with respect to the capital investment.
2. Ridership on the transit line should be maximized.
3. Service on the system should be comfortable and convenient.
4. The transit line should extend as far as possible to promote development and accessibility.
5. The transit line should divert as many auto users as possible during the peak hour in order to reduce highway congestion.

Step 2. Develop the alternatives that will be tested. In this case, five alternatives have been identified as feasible candidates. These vary in length from 5 to 8 miles. The alignment; the amount of the system below-, at-, and above-grade; vehicle size; headways; number of trains; and other physical and operational features of the line are determined in this step.

Step 3. Define an appropriate measure of effectiveness for each objective. For the objectives listed in Step 1, the following measures of effectiveness are selected.

Objective	*Measure of Effectiveness*
1	Net annual revenue divided by annual capital cost
2	Total daily ridership
3	Percent of riders seated during the peak hour
4	Miles of extension into the corridor
5	Number of auto drivers diverted to transit

Step 4. Determine the value of each measure of effectiveness. In this step, the measures of effectiveness are calculated for each alternative. Techniques for demand estimation, as described in Chapter 12, are used to obtain daily and hourly ridership on the line. Cost estimates are developed based on the length of line, number of vehicles and stations, right-of-way costs, electrification, and so forth. Revenues are computed, and ridership volumes during the peak hour are estimated. In some instances, forecasts are difficult to make, so a best or most likely estimate is produced. Since it is the comparative performance of each alternative that is of interest, relative values of effectiveness measures can be used. Estimated values achieved by each criterion for each of the five alternatives are shown in Table 13.5.

Step 5. Determine the relative weight for each objective. This step requires a subjective judgment on the part of the group making the evaluation and will vary among individuals and vested interests. One approach is to allocate the weights on a 100-point scale (just as would be done in developing final grade averages for a course). Another approach is to rank each objective in order of importance and then use a formula of proportionality to obtain relative weights. In this example, the objectives are ranked as shown in Table 13.6 using a 100-point scale. The weighting factor is determined by assigning the value n to the highest ranked alternative, $n - 1$ to the next highest (and so forth), and computing a relative weight as

$$K_j = \frac{W_j}{\sum_{j=1}^{n} W_j} \tag{13.10}$$

Table 13.5 Estimated Values for Measures of Effectiveness

Number	*Measure of Effectiveness*	*Alternatives* *I*	*II*	*III*	*IV*	*V*
1	Annual return on investment (%)	13.0	14.0	11.0	13.5	15.0
2	Daily ridership (1000s)	25	23	20	18	17
3	Passengers seated in peak hour (%)	25	35	40	50	50
4	Length of line (mi)	8	7	6	5	5
5	Auto drivers diverted (1000s)	3.5	3.0	2.0	1.5	1.5

Table 13.6 Ranking and Weights for Each Objective

Objective	*Ranking*	*Relative Weight* (W_j)	*Weighting Factor** (×100)
1	1	5	30
2	2	4	24
3	3	3	17
4	3	3	17
5	4	2	12
Total		17	100

*Rounded to whole numbers to equal 100.

where

K_j = weighting factor of objective j
W_j = relative weight for objective j

The resulting values for each objective are shown in Table 13.6. For example, Objective 1, which is to generate revenue, is ranked 1 and the weighted point value is 30. Objective 5, which is to divert auto drivers, is ranked 4 and the weighted point value is 12. Objectives 3 and 4 are weighted equally with a point value of 17.

Other weighting methods (such as by ballot or group consensus) could be used. It is not necessary to use weights that total 100, as any range of values can be selected. The final results are normalized to 100 at the end of the process.

Step 6. Compute a score and ranking for each alternative. The score for each alternative is computed by considering each measure of effectiveness and awarding the maximum score to the alternative with the highest value and a proportionate amount to the other alternatives. Consider the first criterion, return on investment. As shown in Table 13.5, Alternative V achieves the highest value and is awarded 30 points. The value for Alternative I is calculated as (13/15)(30) = 26. The results are shown in Table 13.7. (An alternative approach is to award the maximum points to the highest valued alternative and zero points to the lowest.)

Table 13.7 Point Score for Candidate Transit Lines

Measure of Effectiveness	*Alternatives* I	II	III	IV	V
1	26.0	28.0	22.0	27.0	30.0
2	24.0	22.1	19.2	17.3	16.3
3	8.5	11.9	13.6	17.0	17.0
4	17.0	14.9	12.8	10.6	10.6
5	12.0	10.3	6.9	5.1	5.1
Total	87.5	87.2	74.5	77.0	79.0

The total point score indicates that the ranking of the alternatives in order of preference is I, II, V, IV, and III. Alternatives I and II are clearly superior to the others and are very similar in ranking. These two will bear further investigation prior to making a decision.

Ranking and rating evaluation is an attractive approach because it can accommodate a wide variety of criteria and can incorporate various viewpoints. Reducing all inputs to a single number is a convenient way to rate the alternatives. The principal disadvantage is that the dependence on a numerical outcome masks the major issues underlying the selection and tradeoffs involved.

Another problem with ranking methods is that the mathematical form for the rating value (Eq. 13.9) is a summation of the products of the weight of each criteria and the relative value. For this mathematical operation to be correct, the scale of measurement must be a constant interval. If the relative values are ordinal (listed in a series), the ranking formula cannot be used. Revising the ranking of the objectives and their relative weights also could change results.

There is also the problem of communicating the results to decision makers, since the interpretation is often difficult to visualize. People think in concrete terms and are able to judge alternatives only when they are presented realistically, rather than as numerical values.

The next section describes a more general and comprehensive approach to evaluation that furnishes information for decision making but stops short of computing numerical values for each alternative.

13.3.2 Cost Effectiveness

Cost effectiveness attempts to be comprehensive in its approach while using the best attributes of economic evaluation. In this method, the criteria that reflect the goals of the project are listed separately from project costs. Thus, the project criteria are considered to be measures of its effectiveness, and the costs are considered as the investment required if that effectiveness value is to be achieved. This approach uses data from economic analyses but allows for other intangible effects, such as environmental consequences, which are also measured. The following example illustrates the use of the cost-effectiveness method.

Example 13.3 Evaluating Metropolitan Transportation Plans Using Cost Effectiveness

Five alternative system plans are being considered for a major metropolitan area. They are intended to provide added capacity, improved levels of service, and reductions in travel time during peak hours. Plan A retains the status quo with no major improvements, Plan B is an all-rail system, Plan C is all highways, Plan D is a mix of rail transit and highways, and Plan E is a mix of express buses and highways. An economic evaluation has been completed for the project, with the results shown in Table 13.8.

Plan B, the all-rail system, and Plan D, the combination rail and highway system, have an incremental BCR of less than 1, whereas Plan C, all highways, and Plan E, highways and express buses, have an incremental BCR greater than 1. These results

Table 13.8 Benefit–Cost Comparisons for Highway and Transit Alternatives

Plan Comparisons	*Annual Cost Difference ($ million)*	*Annual Savings ($ million)*	*BCR*
A versus B	28.58	21.26	0.74
A versus C	104.14	116.15	1.12
C versus D	22.66	17.16	0.76
C versus E	16.73	19.75	1.18

SOURCE: Adapted from *Alternative Multimodal Passenger Transportation Systems*, NCHRP Report 146, Transportation Research Board, National Research Council, Washington, D.C., 1973

would suggest that the highway–bus alternative (Plan E) is preferable to the highway–rail transit alternatives (Plans B and D).

To examine these options more fully, noneconomic impacts have been determined for each and are displayed as an evaluation matrix in Table 13.9. Among the measures of interest are numbers of persons and businesses displaced, number of fatal and personal-injury accidents, emissions of carbon monoxide and hydrocarbons, and average travel speeds by highway and transit.

Solution: An examination of Table 13.9 yields several observations. In terms of number of transit passengers carried, Plan E ranks highest, followed by Plan B. The relationship between annual cost and transit passengers carried is illustrated in Figure 13.4. This

Table 13.9 Measure of Effectiveness Data for Alternative Highway–Transit Plans

	Plan A	*Plan B*	*Plan C*	*Plan D*	*Plan E*
Measure of Effectiveness	*Null*	*All Rail*	*All Highway*	*Rail and Highway*	*Bus and Highway*
Persons displaced	0	660	8000	8000	8000
Businesses displaced	0	15	183	183	183
Annual total fatal accidents	159	158	137	136	134
Annual total personal injuries	6767	6714	5596	5544	5517
Daily emissions of carbon monoxide (tons)	2396	2383	2233	2222	2215
Daily emissions of hydrocarbons (tons)	204	203	190	189	188
Average door-to-door auto trip speed (mi/h)	15.9	16.2	21.0	21.2	21.5
Average door-to-door transit trip speed (mi/h)	6.8	7.6	6.8	7.6	7.8
Annual transit passengers (millions)	154.2	161.7	154.2	161.7	165.2
Total annual cost ($ millions)	2.58	31.16	106.72	129.38	123.44
Interest rate (%)	8.0	8.0	8.0	8.0	8.0

SOURCE: Adapted from *Alternative Multimodal Passenger Transportation Systems*, NCHRP Report 146, Transportation Research Board, National Research Council, Washington, D.C., 1973

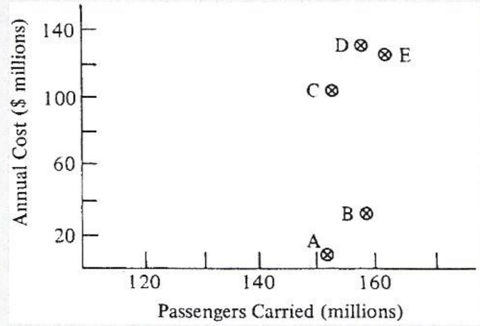


Figure 13.4 Relationship between Annual Cost and Passengers Carried

cost-effectiveness analysis indicates that Plan B produces a significant increase in transit passengers over Plan A. Although Plans C, D, and E are much more costly, they do not produce many more transit riders for the added investment.

Community impacts are reflected in the number of homes and businesses displaced and the extent of environmental pollution. Figure 13.5 illustrates the results for number of businesses displaced, and Figure 13.6 depicts the results for emissions of hydrocarbons.

In terms of businesses displaced versus transit passengers carried, Plans C and D require considerable disruption with very little increase in transit patronage over Plan B,

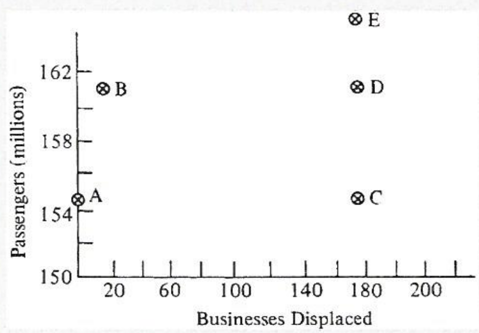


Figure 13.5 Relationship between Passengers Carried and Businesses Displaced

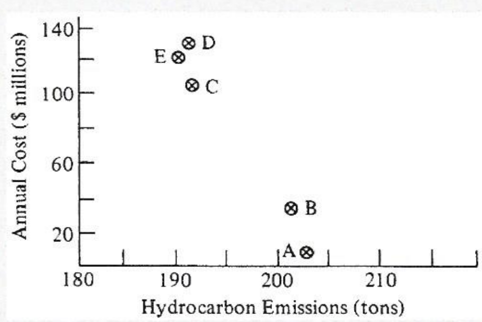


Figure 13.6 Annual Cost versus Hydrocarbon Emissions

which is clearly preferred if the impact on the community is to be minimized. On the other hand, Plan C, which is considerably more costly than Plan B, results in a significant reduction in pollution levels, whereas the other two plans, D and E, although more expensive than C, have little further impact on pollution levels.

The items described are but a few of the many relationships that could be examined. They do, however, illustrate the cost-effectiveness procedure and the various conflicting tradeoffs that can result. One conclusion that seems evident is that, although the BCR for Plans B and D is less than 1, these plans bear further investigation since they produce several environmentally and socially beneficial effects and attract more transit ridership. A sensitivity analysis of the benefit–cost study would show that if the interest rate were reduced to 4 percent or the value of travel time were increased by $0.30 per hour, the rail–transit plan, Plan B, would have a BCR greater than 1.

The cost-effectiveness approach does not yield a recommended result, as do economic methods or ranking schemes. However, it is a valuable tool because it defines more fully the impacts of each course of action and helps to clarify the issues. With more complete information, a better decision should result. Rather than closing out the analysis, the approach opens it up and permits a wide variety of factors to be considered.

13.3.3 Evaluation as a Fact-Finding Process

The preceding discussion of economic and rating methods for evaluation has illustrated the technique and application of these approaches. These so-called rational methods are inadequate when the transportation alternatives create a large number of impacts on a wide variety of individuals and groups. Under these conditions, the evaluation process is primarily one of fact finding to provide the essential information from which a decision can be made. The evaluation procedure for complex projects is illustrated in Figure 13.7 and should include four activities that follow the development and organization of basic data and the identification of the major problems or issues that must be addressed in the evaluation process. The activities are as follows.

Activity 1. View the issues from the perspective of each affected interest group. The thrust of this activity is to view the consequences of proposed alternatives as they affect particular groups and individuals as those groups perceive them. For each interest group, the information should be examined and a statement prepared that indicates how that group will react to each alternative. This step can be considered as a means of understanding where each of the stakeholders are coming from; what their biases, likes, and dislikes are; what problems they represent; and so forth.

Activity 2. View the issues from the perspective of each action. The purpose of this activity is to describe each alternative in terms of its advantages and disadvantages. Each proposed project is discussed from the point of view of community concern, feasibility, equity, and potential acceptability.

Activity 3. View the issues from the perspective of the process as a whole. In this step, all of the alternatives and each of the issues (criteria) are examined together to see if patterns develop from which general statements can be made. For example, there may be one or more alternatives that prove to have so many disadvantages that they can be eliminated. There may be several groups who share the same viewpoint

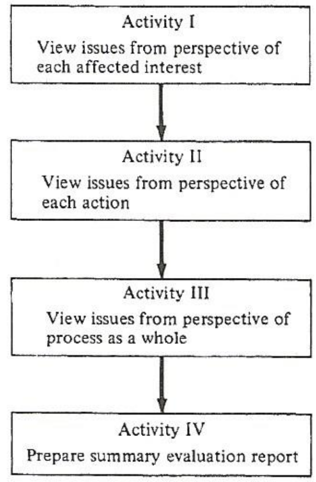


Figure 13.7 Evaluation Procedure for Complex Projects

SOURCE: Redrawn from *Transportation Decision Making,* NCHRP Report 156, Transportation Research Board, National Research Council, Washington, D.C., 1975

or who are in fierce opposition. Compromise solutions may emerge that will reconcile conflicts, or there may be popular alternatives that generate little controversy.

Activity 4. Summarize the results. In this activity, the result of the evaluation is documented and used by decision makers and other interested individuals. The report should include a description of the alternatives, the advantages and disadvantages of each alternative, areas of conflict and of agreement, and identification of the alternatives that have the greatest potential for success in accomplishing major objectives and achieving public acceptance.

This process is comprehensive and goes beyond a simple listing of criteria and alternatives. One essential feature of the approach is that it requires the analyst to furnish values of each measure of effectiveness for each alternative without attempting to reduce the results to a single numerical value. The information is then used to make judgments about the relative merits of each alternative.

13.3.4 Tradeoff and Balance-Sheet Approaches

There are several important conditions that must be met if the difference among alternative projects are to be adequately considered. They are as follows:

1. All alternatives should be evaluated in a framework of common objectives. Measures of effectiveness should be derived from the objectives covering all impact areas.
2. The incidence and timing of impacts on groups and areas should be identified for all impact categories.
3. Standards or accepted impact significance thresholds for measures of effectiveness should be indicated where accepted or required by law.
4. All measures of effectiveness should be treated at an equal level of detail and appropriate scale.
5. Uncertainties or probabilities (or both) should be expressed for each impact category.
6. A sensitivity analysis should be conducted to describe variations in results for alternatives when values of key parameters are changed.

Balance-sheet or tradeoff approaches satisfy these criteria in contrast to economic or weighting schemes, which provide little in the way of comparative information. These approaches display the impacts of plan alternatives to various groups. The method is based on the viewpoint that individuals or groups that review the data will first introduce their own sets of values and weights, and then reach a judgment based on the merits of each alternative using all the data in a disaggregated fashion. Each impact category or goal may have more than one measure of effectiveness. To determine the cost-effectiveness of each impact category in a balance-sheet framework, it is useful to compare proposals with the do-nothing alternative. In this way, the positive and negative impacts of not constructing a new project are fully understood.

13.3.5 Evaluation of Completed Projects

The material on evaluation discussed thus far has dealt with the evaluation of plans, and the focus has been to answer the "what if" questions in sufficient detail so that a good decision will be made. Another form of evaluation is to examine the results of a project after it has been implemented to determine (1) how effective it has been in accomplishing its objectives, (2) what can be learned that is useful for other project decisions, (3) what changes should be made to improve the current situation, or (4) if the project should be continued or abandoned.

The subject of post-evaluation of transportation projects is closely related to the more general topic of experimental design. If, for example, the effects of a particular medical treatment are to be determined, two population groups with similar characteristics are selected: one serving as the control group and the other as the experimental group. Then the treatment is applied to the experimental group but not to the control group. Differences are measured before and after treatment for both groups, and the net effect is considered to be the result of the treatment itself.

Example 13.4 Evaluating the Effect of Bus Shelters on Transit Ridership

A transit authority wishes to evaluate the effectiveness of new bus shelters on transit ridership, as well as acceptance by the community. A series of new shelters were built along one bus route but not along other lines. Do the shelters affect ridership?

Solution: Bus ridership was measured before and after the shelters were installed on the test line and on a control line where nothing new was added. Both lines serve similar neighborhoods. The ridership results are shown in Table 13.10. The line with new shelters increased ridership by 13.3 percent, whereas the line without shelters increased by only 2.5 percent. It should be stressed that only in the absence of any other factors can we conclude that the effect of the new shelters was to increase ridership by (13.3 − 2.5) = 10.8%.

Table 13.10 Transit Ridership

	Before	*After*	*Change (%)*
Line A: new shelters	1500	1700	13.3
Line B: no shelters	1950	2000	2.5

Another tool for evaluation of completed projects is to conduct a survey of users of the new facility. The questionnaire can probe in greater depth why riders use the facility and to what extent the project improvement influenced their choice. In the bus shelter example, a survey of bus riders would inquire if passengers were longtime bus riders or are new riders. If new riders, the survey would ask the reasons for riding to find out how many of the new riders considered the new shelters a factor. (Other reasons for riding could be that the rider is new in the neighborhood, his or her car is being repaired, gasoline prices have just gone up, and so forth.) The survey would also ask the old riders to comment on the new shelters. Thus, the survey would corroborate the before-and-after ridership data as well as furnish additional information about the riders themselves and how they reacted to the new project. This information would be useful in deciding whether or not to implement a bus shelter program for the entire city.

In the transportation field, it is difficult to achieve an experimental design with a well-defined control and experimental group because (1) transportation projects influence a wide range of outcomes, (2) implementation times are very long and therefore funds may not be available to gather before data, (3) a control group is difficult to identify, and (4) changes that occur over a long time period are difficult to connect with a single event, such as a new transportation system.

An example of a post-evaluation for a major transportation project is the Bay Area Rapid Transit (BART) impact study. The approach to post-evaluation in this instance was to predict the effect on the region of measures such as air pollution, noise, travel time, and so forth without the rail transit system and then measure the actual amounts with the rapid transit system in place. In this approach, a control group was impossible to obtain, but in its place a forecast was made of conditions in the region if a rapid transit system had not been constructed. The obvious difficulty with this method is that it depends on the accuracy of the forecast and must take into account all the changes that have occurred in the region that might have an effect on the impact measures of interest.

Another type of transportation project post-evaluation is to make comparisons between different systems or technologies that serve similar travel markets. These comparisons can be helpful to decision makers in other localities because they furnish useful information about what happened in an actual situation. A post-evaluation study can be useful because it can consider the actual results for many variables, whereas a pre-project evaluation of a mode or technology tends to focus primarily on cost factors or is based on hypothetical situations that require many questionable assumptions.

Example 13.5 Comparing the Effectiveness of Bus and Rail Transit

Compare the effectiveness of rail and bus based on the experience of a rail transit line serving downtown Philadelphia and a suburb of New Jersey with an express bus line connecting downtown Washington, D.C., with the Virginia suburbs. The rail line, known as the Lindenwold Line, serves 12 stations with 24-hour service per day, whereas the busway, known as the Shirley Highway, extends for 11 miles, with no stations along the way and with bus service provided on exclusive lanes only during the peak hour. Both systems serve relatively low-density, auto-oriented residential areas with heavy travel during the peak hours.

Solution: To determine the relative effectiveness, a comparative analysis of each project was made after they had been in operation for several years. Measures of effectiveness were considered from the viewpoint of the passenger, the operator, and the community. Data were collected for each system and for each measure of effectiveness. A detailed evaluation for each parameter was prepared that both described how each system performed and discussed its advantages and disadvantages. To illustrate, consider the evaluation of one service parameter—*reliability*—expressed as schedule adherence. The variance from scheduled travel times may result from traffic delays, vehicle breakdowns, or adverse weather conditions. It depends mostly on the control that the operator has over the entire system. By far, the most significant factor for reliability is availability of exclusive rights-of-way.

- *Lindenwold:* That year, 99.15 percent of all trains ran less than 5 min late, and the following year the figure was 97 percent.
- *Shirley:* Surveys conducted over a 4-day period indicated that 22 percent arrived before the scheduled time, 32 percent were more than 6 min late, and only 46 percent arrived at the scheduled time within a 5-min period.
- *Comparison:* The Lindenwold Line (rail) is superior to the Shirley Highway (bus) with respect to reliability.

A summary of the comparative evaluations of the two systems is shown in Table 13.11.

A detailed analysis of the results would indicate that each system has advantages and disadvantages. The principal reasons why the rail system appears more attractive than the bus are that it provides all-day service, it is simpler to understand and use, and it produces a higher quality of service.

Table 13.11 Comparative Evaluations of Completed Rail and Bus Transit

Measure of Effectiveness	*Lindenwold (Rail)*	*Shirley (Bus)*	*Higher Rated System*
Investment cost	Very poor	Fair	Bus
Operating cost	Good	Fair	Rail
Capacity	Good	Poor	Rail
Passenger attraction	Very good	Good	Rail
System impact	Very good	Good	Rail

SOURCE: Adapted from V. R. Vuchic and R. M. Stanger, "Lindenwold Rail Line and Shirley Busway: A Comparison," *Highway Research Record,* 459, Transportation Research Board, National Research Council, Washington, D.C., 1973, pp 13-28

13.3.6 Evaluating Effects of Transportation on Social and Natural Systems

A comparative evaluation of the impacts of a transportation project involves the following sequence.

Step 1. Assess the need for the project.
Step 2. Conduct a feasibility analysis of the alternatives.
Step 3. Analyze the impact of the project from the following points of view.
(a) Transportation system effects
(b) Social and economic effects
(c) Natural systems effects

Step 4. Organize the results of the evaluation in a manner that is clear and understandable by the affected parties, such as citizens, stakeholders, and decision makers.

Step 1: Assess the Need for the Project

This step addresses the question: Why do it at all? That is, how does the proposed project advance the stated goals and objectives and does the project represent the best use of funds when compared with other options?

Step 2: Conduct a Feasibility Analysis of the Alternatives

This step addresses the question: Why do it this way? That is, has the project been demonstrated to be a feasible one from an engineering perspective? What are the costs involved in the project? Are there other methods or approaches that could achieve a similar result at a lower cost in time and money? Should the project be included as a budget item for implementation or deferred to a later date?

Step 3: Analyze the Impact of the Project

This step addresses the question: If the project is feasible, what will be its impact on affected groups? These include the users of the transportation improvement, the community, and other stakeholders who will be impacted by the construction of the project. These effects are categorized into three major effects.

- Transportation system effects
- Social and economic effects
- Natural systems effects

A comprehensive treatment of these effects and each element is contained in the textbook, *Transportation Decision Making: Principles of Project Evaluation and Programming*. Each of these is summarized as follows.

Step 3 (a): Transportation System Effects. These are effects experienced by the travelers who use the transportation facility, such as motorists, transit riders, and commercial vehicles. They comprise the following elements.

- Changes in travel time
- Changes in safety
- Changes in vehicle operating costs

To determine system changes, methods of analysis in areas of traffic flow theory, safety engineering, and cost analysis are used. Many of these topics are covered in this textbook and other references.

Step 3 (b): Social and Economic Effects. These are analyzed to determine the impact that a transportation project could have on the community and its residents. These studies are also conducted to meet federal and state requirements regarding environmental impact, civil rights, and environmental justice. They comprise the following elements.

- Accessibility
- Community cohesion
- Economic development

- Traffic noise
- Visual quality
- Property values

To determine the social and economic effects of a transportation project, a variety of methods are used. Many of these areas require special expertise in professional fields such as economics, demography, sociology, geography, geographic information systems (GIS), architecture, and urban planning. NCHRP Report 456 can serve as a useful guide for conducting these impact evaluations.

Step 3 (c): Natural Systems Effects. These refer to those impacts of transportation projects that are related to the environment within which the project will be located. For example, there are short-term effects, such as those caused by displacement of natural soil during construction, and long-term effects related to the sustainability of energy resources and climate change. Among the natural elements that may be affected are

- Air and water quality
- Endangered species
- Wildlife
- Greenhouse gas emissions
- Archeological sites
- Energy conservation
- Areas of cultural or historic significance

To explain natural system effects from transportation projects, some of which are described in NCHRP Report 532, a broad range of expertise is required from many fields of science, medicine, fine arts, and engineering. These include air and water quality modeling, environmental science, chemistry, history, archaeology, veterinary medicine, wildlife management, and ecology. Each of the impacts are relevant to categories specified in federal regulations discussed in Chapter 11, such as the National Environmental Policy Act (NEPA) and regulations for Environmental Impact Statements (EIS) as specified by the U.S. Department of Transportation.

13.4 SUMMARY

The evaluation process for selecting a transportation project has been described. Various methods have been presented that, when used in the proper context, can assist a decision maker in making a selection. The most important attribute of an evaluation method is its ability to correctly describe the outcomes of a given alternative. The evaluation process begins with a statement of the goals and objectives of the proposed project, and these are converted into measures of effectiveness. Evaluation methods differ by the way in which measures of effectiveness are considered.

Economic evaluation methods require that each measure of effectiveness be converted into dollar units. Numerical ranking methods require that each measure of effectiveness be translated to an equivalent score. Both methods produce a single number to indicate the total worth of the project. Cost-effectiveness methods require only that each measure of effectiveness be displayed in matrix form, and it is the task of the analysts to develop relationships between various impacts and the costs involved. For projects with many impacts that will influence a wide variety of individuals and groups, the evaluation process is essentially one of fact finding, and the projects must be considered from the viewpoint of the stakeholders and community. The reasons for selecting a project will include many factors in addition to simply how the project performs. A decision maker must consider issues such as implementation, schedules, financing, and legal and political matters.

When a project has been completed and has been in operation for some time, a post-evaluation can be a useful means to examine the effectiveness of the results. To conduct a post-evaluation, it is necessary to separate the effect of the project on each measure of effectiveness from other influencing variables. A standard procedure is the use of a control group for comparative purposes, but this is usually not possible for most transportation projects. A typical procedure is to compare the results with a forecast of the region without the project in place. Post-evaluations also can be used to compare alternative modes and technologies, using a wide range of measures of effectiveness.

The usefulness of an evaluation procedure is measured by its effectiveness in helping decision makers arrive at a solution that will best accomplish the intended goals.

PROBLEMS

13-1 What is the main objective of conducting a transportation project evaluation?

13-2 Describe four basic issues that should be considered prior to selection of an evaluation procedure.

13-3 List the basic criteria used for evaluating transportation alternatives. What units are used for measurement?

13-4 Average demand on a rural roadway ranges from zero to 500 veh/day when the cost per trip goes from $1.50 to zero.

(a) Calculate the net user benefits per year if the cost decreases from $1.00 to $0.75/trip (assume a linear demand function).

(b) Compare the value calculated in (a) with the benefits as calculated in typical highway studies.

13-5 A ferry is currently transporting 300 veh/day at a cost of $1.50/vehicle. The ferry can attract 600 more veh/day when the cost/veh is $1.00. Calculate the net user benefits/year if the cost/veh decreases from $1.10 to $0.95.

13-6 What are the two components of the cost of a transportation facility improvement? Describe each.

13-7 Estimate the average unit costs for (a) operating a standard vehicle on a level roadway, (b) travel time for a truck company, (c) single-vehicle property damage, (d) personal injury, and (e) fatality.

13-8 An incident that occurs on a particular highway results in traffic incurring an average delay of one hour per vehicle. An estimated 2000 vehicles are impacted by the incident. If the distribution of traffic is comprised of 5 percent five-axle trucks, 2 percent three-axle trucks, 4 percent six-tire trucks, 2 percent four-tire trucks, 4 percent medium autos for business purposes, 3 percent small autos for business purposes, and the remainder automobiles for personal purposes, what is the value of the total delay incurred by the traffic?

13-9 Derive the equation to compute the equivalent annual cost given the capital cost of a highway, such that $A = (A/P) \times P$, where A/P is the capital recovery factor. Compute the equivalent annual cost if the capital cost of a transportation project is $100,000, annual interest = 10%, and n = 15 years.

13-10 A highway project is expected to cost $1,700,000 initially. The annual operating and maintenance cost after the first year is $5000 and will increase by $500 each year for a project lifespan of 20 years. At the end of the tenth year, the project must be resurfaced at a cost of $300,000.

(a) Calculate the present worth of costs for this project over a 20-year period if the annual interest rate is 5 percent.
(b) Convert the value obtained in (a) to equivalent uniform annual costs.

13-11 The concepts applied in economic evaluation to address the time-dependent value of money can also be applied to other phenomena, such as growth in traffic volume. The traffic volume on a local highway was 3510 vehicles per day on an average day in 2012. Based on historical trends, the traffic volume is expected to increase by 3 percent per year for the foreseeable future. What is the expected traffic volume in 2022?

13-12 Three transportation projects have been proposed to increase the safety in and around a residential neighborhood. Each project consists of upgrading existing street signing to highly retroreflective sheeting to increase visibility. The following table shows the initial construction costs, annual operating costs, useful life of the sheeting, and salvage values for each alternative. Assume that the discount rate is 10 percent. Calculate the present worth for each alternative and determine the preferred project based on the economic criteria.

Alternative	*Initial Construction Cost ($)*	*Annual Operations and Maintenance Costs ($)*	*Useful Life (years)*	*Salvage Value ($)*
1	19,000	2,500	10	3,000
2	8,000	4,000	5	900
3	20,000	2,500	10	4,600

13-13 Two designs have been proposed for a short-span bridge in a rural area, as shown in the following table. The first proposal is to construct the bridge in two phases (Phase I now and Phase II in 25 years). The second alternative is to construct it in one phase. Assuming that the annual interest rate is 4 percent, use present worth analysis to determine which alternative is preferred.

Alternative	*Construction Costs ($)*	*Annual Maintenance Costs ($)*	*Service Period (yr)*
A (Phase 1)	14,200,000	75,000	1–50
A (Phase 2)	12,600,000	25,000	26–50
B	22,400,000	100,000	1–50

13-14 Three designs have been proposed to improve traffic flow at a major intersection in a heavily traveled suburban area. The first alternative involves improved traffic signaling. The second alternative includes traffic-signal improvements and intersection widening for exclusive left turns. The third alternative includes extensive reconstruction, including a grade separation structure. The construction costs, as well as annual maintenance and user costs, are listed in the following table for each alternative. Determine which alternative is preferred based on economic criteria if the analysis