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

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

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

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

$$i = 2.7\%$$

Since the increased investment in Alternative III yields an ROR less than 3%, 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 EUAC 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 the user groups that benefit from a project and those that pay.
- Failing to distinguish between groups that benefit and those that lose.
- Considering all costs, including external costs.

For these reasons, economic evaluation methods should be used either in narrowly focused projects or as one of many inputs in 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 criteria 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 numbers of stops. Estimated values achieved by each criterion for each of the five alternatives are shown in Table 13.5. 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 five major objectives should be achieved by the new transit line.

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.

Table 13.5 Estimated Values for Measures of Effectiveness

		Alternatives				
Number	*Measure of Effectiveness*	*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

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 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. 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

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

where

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

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.

The resulting values for each objective are shown in Table 13.6. Objective 1, which is to generate revenue, will be worth 30 points, whereas Objective 5, which is to divert auto drivers, is weighted 12 points. 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, and the final results normalized to 100 at the end of the process.

Step 5. 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.

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. Table 13.5 shows that 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.)

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.

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

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 criteria weight and the relative value. For this mathematical operation to be correct, the scale of measurement must be a constant interval (for example, temperature). If the ranking values are ordinal (such as the numbering of a sports team), the ranking formula cannot be used. Results also could be changed by revising the ranking of the objectives and their relative weights.

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 analysis but permits 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 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 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

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.

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.

Plan B, 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.

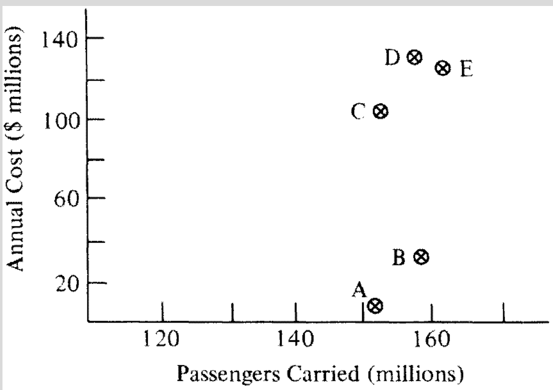

Figure 13.4 Relationship between Annual Cost and Passengers Carried

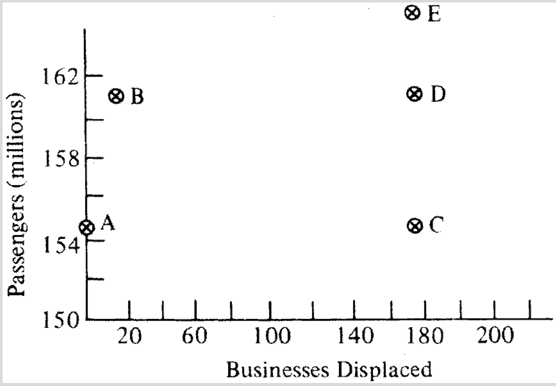

Figure 13.5 Relationship between Passengers Carried and Businesses Displaced

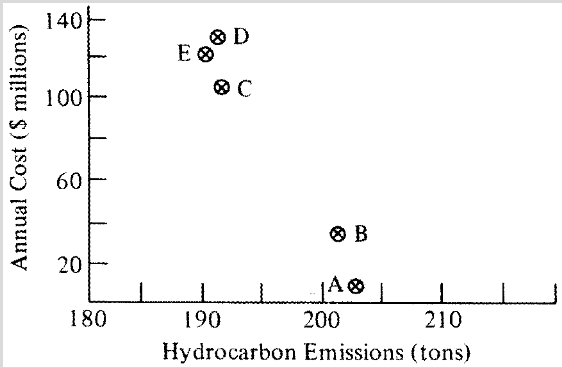

Figure 13.6 Annual Cost versus Hydrocarbon Emissions

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 trade-offs 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% 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.