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 other 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

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

where

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

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 equal 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

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

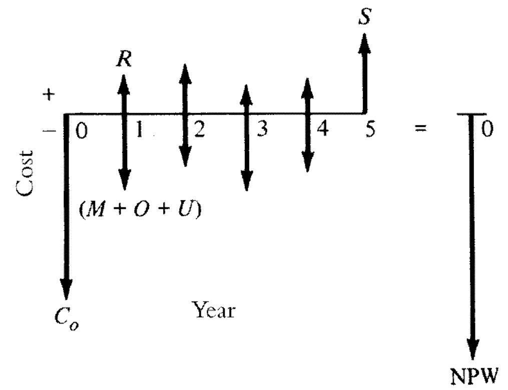

Figure 13.3 Typical Cash Flow Diagram for a Transportation Alternative and Equivalence as Net Present Worth

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, we have converted a time stream of costs and revenues 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 $P/F - i - N$, where P is the present value given the future amount F, and N is the years of service life.

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,

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

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 is made for \$5000 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

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

Formula 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.

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	0.7414	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

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 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

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 $C_{2/1}$ is the rate of return. 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 for comparison 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

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

50 years and the discount rate is 3%, which alternative should be selected? Solve the problem using the four methods for economic analysis.

Solution:

- Compute the NPW of each project.

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

$$\begin{aligned}
NPW_{I} &= -185{,}000 + (-1500 + 5000 + 3000 + 500)(P/A - 3 - 50) \\
&= -185{,}000 + (7000)(25.729) = -185{,}000 + 180{,}103 \\
&= -4897 \\
NPW_{II} &= -220{,}000 + (-2500 + 5000 + 6500 + 500)(P/A - 3 - 50) \\
&= -220{,}000 + (9500)(25.729) = -220{,}000 + 244{,}425 \\
&= +24{,}465 \\
NPW_{III} &= -310{,}000 + (-3000 + 7000 + 6000 + 2800)(P/A - 3 - 50) \\
&= -310{,}000 + (12{,}800)(25.729) = -310{,}000 + 329{,}331 \\
&= +19{,}331
\end{aligned}$$

The project with the highest NPW is alternative II.

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

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

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).

$$BCR_{1/DN} = \frac{180{,}103}{185{,}000} = 0.97$$

Since $BCR_{1/DN}$ is less than 1, we would not build Alternative I.

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

$$BCR_{II/DN} = \frac{244{,}425}{220{,}000} = 1.11$$

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

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

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

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.)

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

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

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

$$i = 2.6\%$$

Since the ROR is lower than 3% 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%, selecat 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%, 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.