Chapter 8—Prioritize Projects
2010 Highway Safety Manual

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8.1. INTRODUCTION

Chapter 8 presents methods for prioritizing countermeasure implementation projects. Prior to conducting prioritization, one or more candidate countermeasures have been identified for possible implementation at each of several sites, and an economic appraisal has been conducted for each countermeasure. Each countermeasure that is determined to be economically justified by procedures presented in Chapter 7 is included in the project prioritization process described in this chapter. Figure 8-1 provides an overview of the complete Roadway Safety Management process presented in Part B of the manual.

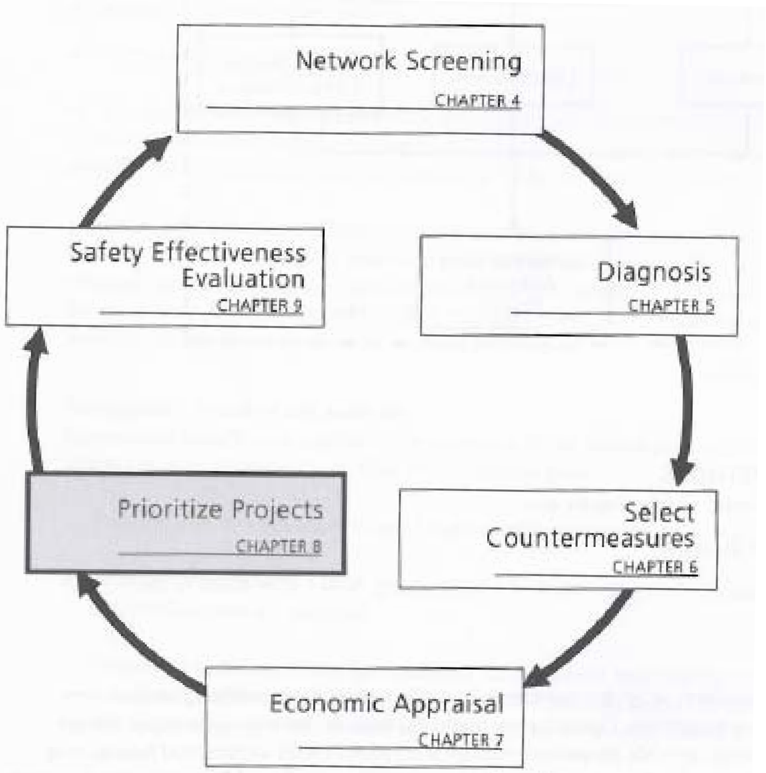

Figure 8-1. Roadway Safety Management Process Overview

In the HSM, the term “prioritization” refers to the review of possible projects or project alternatives for construction and the development of an ordered list of recommended projects based on the results of ranking and optimization processes. “Ranking” refers to an ordered list of projects or project alternatives based on specific factors or project benefits and costs. “Optimization” is used to describe the process by which a set of projects or project alternatives are selected by maximizing benefits according to budget and other constraints. This chapter includes overviews of simple ranking and optimization techniques for prioritizing projects. The project prioritization methods presented in this chapter are primarily applicable to developing optimal improvement programs across multiple sites or for an entire roadway system, but they can also be applied to compare improvement alternatives for a single site. This application has been discussed in Chapter 7. Figure 8-2 provides an overview of the project prioritization process.

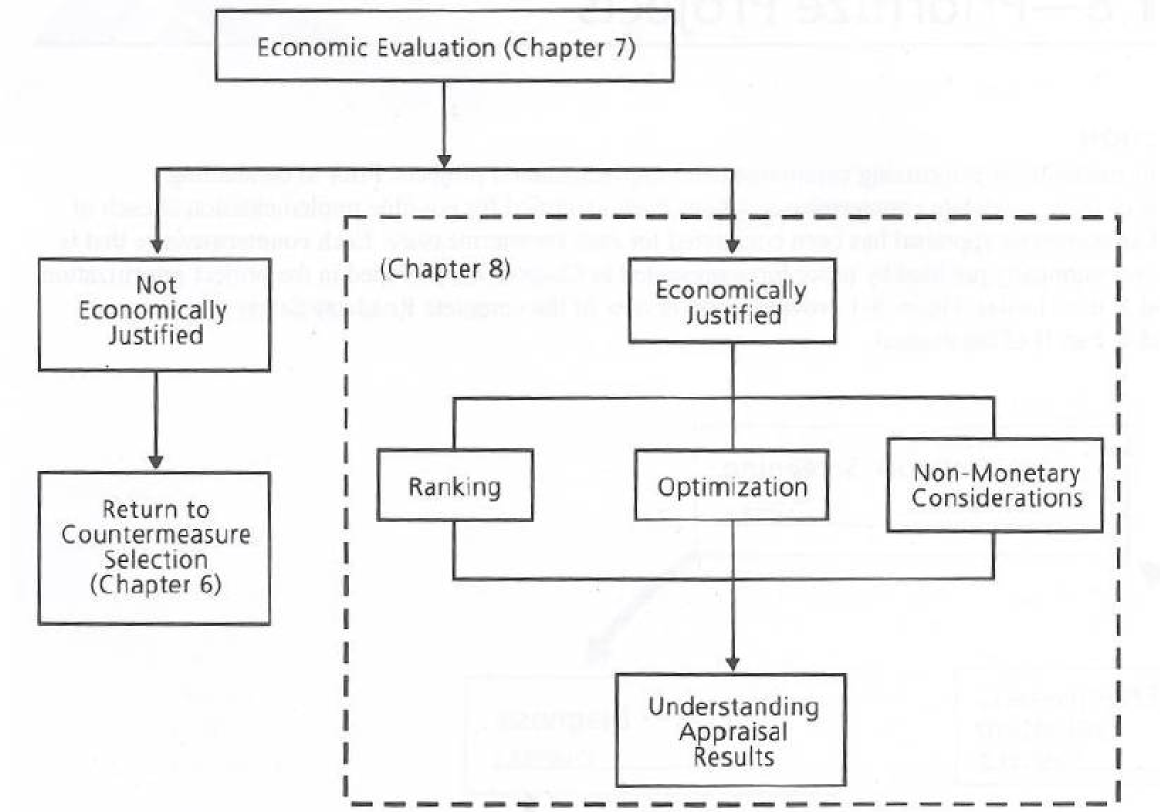

Figure 8-2. Project Prioritization Process

8.2. PROJECT PRIORITIZATION METHODS

The five prioritization methods presented in this chapter are:

- Ranking by cost effectiveness measures
- Net present value ranking
- Benefit cost ratio ranking
- Incremental benefit cost analysis ranking
- Optimization methods

Ranking by cost effectiveness measures, net present value, or benefit cost analysis provides a prioritized list of projects based on a chosen criterion. Benefit cost ratio and incremental benefit cost ratio can define an optimal set of projects for limited budget. Optimization methods, such as linear programming, integer programming, and dynamic programming, provide project prioritization consistent with benefit cost and incremental benefit cost analyses, also taking account of the impact of budget constraints in creating an optimized project set. Multi-objective resource allocation can consider the effect of non-monetary elements, including decision factors other than crash reduction, and can optimize based on several factors.

The net present value (NPV) method ranks independent projects. However, it provides an economically optimal budget constrained solution only if their project costs are equal. The benefit cost ratio (BCR) method ranks and selects from a set of independent projects, presented in Chapter 7. Incremental benefit cost (IBCR) analysis is an extension of the BCR method used to rank and select mutually exclusive projects.

Independent versus Mutually Exclusive Projects

The method used to rank and select alternative projects depends on whether they are "independent" or "mutually exclusive."

- Independent Projects – these are projects whose performance does not impact the other independent projects, usually at separate sites.
- Mutually Exclusive – these are projects whose performance precludes the use of other mutually exclusive projects, often at the same site, such as an intersection.

Examples of independent projects are those at separate roadway sections or spots. Mutually exclusive project examples are represented by various alternatives at a railroad crossing, such as, cross bucks with a stop sign, gates with flashing signals, and an over-crossing.

Independent and mutually exclusive projects can occur at a site. For example, the mutually exclusive projects at an intersection could include a left turn signal over a left turn bay, replacement of the intersection with a roundabout, and installation of an interchange. A separate and independent project at this location could be the increased illumination of the intersection and its approaches to improve pedestrian safety.

Optimization Methods

Linear programming, integer programming, and dynamic programming are closely related to the net present value (NPV) method presented in Chapter 7. There is no generalized multiple-site method equivalent to the cost-effectiveness method presented in Chapter 7.

A conceptual overview of each prioritization method is presented in the following sections. Computer software programs are needed to efficiently and effectively use many of these methods, due to their complexity. For this reason, this chapter does not include step-by-step procedures for these methods. References to additional documentation regarding these methods are provided.

8.2.1. Ranking Procedures

Ranking by Cost Effectiveness Measures

The simplest method for establishing project priorities involves ranking projects or project alternatives by the following measures (identified in Chapter 7), including:

- Monetary value of project benefits,
- Number of total crashes reduced,
- Number of fatal and incapacitating injury crashes reduced,
- Number of fatal and injury crashes reduced, and

- Cost-effectiveness index.

As an outcome of a ranking procedure, the project list is ranked high to low on any one of the above measures. Many simple improvement decisions, especially those involving only a few sites or a very limited number of project alternatives for each site can be made by reviewing rankings based on two or more of these criteria. These rankings do not provide the greatest monetary safety return for the invested budget. Further, because these methods do not account for competing priorities, budget constraints, or other project impacts, they are inadequate for situations with multiple competing priorities.

Ranking by Economic Effectiveness Measures

The final decisions on which alternatives should be selected must take account of economic resources and the available budget. The measures for ranking the economic effectiveness can be based on the following:

- Total project costs – where project benefits for each alternative are equal,
- Monetary value of project benefits – where project costs of each alternative are equal,
- Net present value (or net present worth) – where project costs are equal for each alternative,
- Rate of return – yields same ranking as benefit cost ratio (covered in engineering economics references),
- Benefit cost ratio – used where projects are independent, typically at separate sites, and
- Incremental benefit cost ratio – used where each alternative project precludes the use of all other projects, i.e., mutually exclusive.

Objective for Ranking Alternatives Economically

The objective for ranking a set of alternatives is to get the greatest return in monetary safety benefits for the available budget, from the selected set of ranked alternatives. The criterion for selection is the greatest benefit for each dollar of cost invested at each step, i.e., the greatest benefit cost ratio.

Net Present Value Ranking

The net present value (NPV) can be used to rank alternatives only if the project costs are equal. Otherwise, it cannot provide an optimal ranking of projects with a limited budget. It reflects the net safety benefits derived from investment in a project, but not the effectiveness of that investment.

Benefit Cost Ratio Ranking

The benefit cost ratio (BCR) is best used to rank independent alternatives, which are typically located at separate sites. Any project with a benefit cost ratio (BCR) of greater than “1” is economically justified. However, at times an arbitrarily higher benefit cost ratio is adopted as a minimum, such as 1.2, since a BCR of “1” indicates that benefits equal costs with all the associated benefit values and interest rate assumed. The alternative with the highest benefit cost ratio is ranked first, and ranking proceeds with the benefit cost ratios in decreasing order.

Incremental Benefit Cost Analysis Ranking

Incremental benefit cost analysis (IBCR) is an extension of the benefit cost ratio (BCR) method presented in Chapter 7. The incremental benefit cost ratio method should be used only where any one alternative precludes the use of all other alternatives, i.e., mutually exclusive, typically at a site. The following steps describe the method in its simplest form:

1. Perform a BCR evaluation for each individual improvement project as described in Chapter 7.
2. Arrange projects with a BCR greater than 1.0 in increasing order based on their estimated project cost. The project with the smallest cost is listed first.
3. Beginning at the top of the list, calculate the difference between the first and second project's benefits. Similarly, calculate the difference between the costs of the first and second projects. The differences between the benefits of the two projects and the costs of the two are used to compute the BCR for the incremental investment, that is, the incremental benefit cost ratio (IBCR).

$$\mathrm{IBCR} = \frac{\mathrm{PVB}_2 - \mathrm{PVB}_1}{\mathrm{PVC}_2 - \mathrm{PVC}_1} \qquad \textbf{(Eq. 8-1)}$$

4. Beginning with the least cost project, Project i, determine the incremental benefit cost ratio (IBCR) for the incremental investment to the next higher cost project. If the next higher cost project, Project j, has an IBCR greater than 1.0, that the project with the higher cost is temporarily selected. If the IBCR for the incremental investment is less than 1.0, the project with the lower cost is compared to the next project in the list, Project k. This process continues until a higher cost project with an IBCR greater than 1 is found, and temporarily selected.

   Note that the BCR for each project is not taken into account, and projects with a high BCR can be replaced by a project with a lower BCR, if the IBCR from i to j is greater than 1. The objective of the incremental benefit cost method is to continually search for projects that increase the safety benefits by more than the costs incurred, that is, IBCR > 1.0.
5. Repeat this process comparing the temporarily selected project with the next higher cost project, or projects. The project selected in the final pairing is considered the best economic investment from the mutually exclusive set of projects.

Since the incremental benefit cost ratio method should be applied only where selection of one project precludes the use of others, i.e., mutually exclusive, the last project selected is best for the site. There may be instances where two projects have the same cost estimates resulting in an incremental difference of zero for the costs. An incremental difference of zero for the costs leads to a zero in the denominator for the BCR. If such an instance arises, the project with the greater benefit is selected. Incremental benefit cost analysis does not explicitly impose a budget constraint, so the project costs must be compared to the budget at each step to assure it is affordable.

It is possible to perform this process manually for a simple application; however, the use of a spreadsheet or special purpose software to automate the calculations is the most efficient and effective application of this method. An example of incremental benefit cost analysis software used for highway safety analysis is the Roadside Safety Analysis Program (RSAP), which is widely used to establish the economic justification for roadside barriers and other roadside improvements (3).

8.2.2. Optimization Methods

At a highway network level, a jurisdiction may have a list of improvement projects that are already determined to be economically justified, but there remains a need to determine the most cost-effective set of improvement projects that fit a given budget. Optimization methods are used to identify a project set that will maximize benefits within a fixed budget and other constraints. Thus, optimization methods can be used to establish project priorities for the entire highway system or any subset of the highway system.

It is assumed that all projects or project alternatives to be prioritized using these optimization methods have first been evaluated and found to be economically justified (i.e., project benefits are greater than project costs). The method chosen for application will depend on:

- The need to consider budget or other constraints, or both, within the prioritization, and
- The type of software accessible, which could be as simple as a spreadsheet or as complex as specialized software designed for the method.

Basic Optimization Methods

There are three specific optimization methods that can potentially be used for prioritization of safety projects. These are:

- Linear programming (LP) optimization
- Integer programming (IP) optimization
- Dynamic programming (DP) optimization

Each of these optimization methods uses a mathematical technique for identifying an optimal combination of projects or project alternatives within user-specified constraints (such as an available budget for safety improvement). Appendix 8A provides a more detailed description of these three optimization methods.

In recent years, integer programming is the most widely used of these three optimization methods for highway safety applications. Optimization problems formulated as integer programs can be solved with Microsoft Excel or with other commercially available software packages. A general-purpose optimization tool based on integer programming is available in the FHWA Safety Analyst software tools for identifying an optimal set of safety improvement projects to maximize benefits within a budget constraint (www.safetyanalyst.org). A special-purpose optimization tool known as the Resurfacing Safety Resource Allocation Program (RSRAP) is available for identifying an optimal set of safety improvements for implementation in conjunction with pavement resurfacing projects (2).

Multi-Objective Resource Allocation

The optimization and ranking methods discussed above are all directly applicable to project prioritization where reducing crashes is the only objective being considered. However, in many decisions concerning highway improvement projects, reducing crashes is just one of many factors that influence project selection and prioritization. Many highway investment decisions that are influenced by multiple factors are based on judgments by decision makers once all of the factors have been listed and, to the extent feasible, quantified.

A class of decision-making algorithms known as multi-objective resource allocation can be used to address such decisions quantitatively. Multi-objective resource allocation can optimize multiple objective functions, including objectives that may be expressed in different units. For example, these algorithms can consider safety objectives in terms of crashes reduced; traffic operational objectives in terms of vehicle-hours of delay reduced; air quality benefits in terms of pollutant concentrations reduced; and noise benefits in terms of noise levels reduced. Thus, multi-objective resource allocation provides a method to consider non-monetary factors, like those discussed in Chapter 7, in decision making.

All multi-objective resource allocation methods require the user to assign weights to each objective under consideration. These weights are considered during the optimization to balance the multiple objectives under consideration. As with the basic optimization methods, in the multi-objective resource allocation method an optimal project set is reached by using an algorithm to minimize or maximize the weighted objectives subject to constraints, such as a budget limit.

Examples of multi-objective resource allocation methods for highway engineering applications include Interactive Multi-objective Resource Allocation (IMRA) and Multicriteria Cost-Benefit Analysis (MCCBA) (1,4).

8.2.3. Summary of Prioritization Methods

Table 8-1 provides a summary of the prioritization methods described in Section 8.2.

The methods presented in this chapter vary in complexity. Depending on the purpose of the study and access to specialized software for analysis, one method may be more appropriate than another. Each method is expected to provide valuable input into the roadway safety management process.

8.3. UNDERSTANDING PRIORITIZATION RESULTS

The results produced by these prioritization methods can be incorporated into the decision-making process as one key, but not necessarily definitive, piece of information. The results of these prioritization methods are influenced by a variety of factors including:

- How benefits and costs are assigned and calculated;
- The extent to which the evaluation of costs and benefits are quantified;
- The service lives of the projects being considered;
- The discount rate (i.e., the minimum rate of return); and
- The confidence intervals associated with the predicted change in crashes.

There are also non-monetary factors to be considered, as discussed in Chapter 7. These factors may influence the final allocation of funds through influence on the judgments of key decision makers or through a formal multi-objective resource allocation. As with many engineering analyses, if the prioritization process does not reveal a clear decision, it may be useful to conduct sensitivity analyses to determine incremental benefits of different choices.

8.4. SAMPLE PROBLEMS

The sample problems presented here illustrate the ranking of project alternatives across multiple sites. The linear programming, integer programming, dynamic programming, and multi-objective resource allocation optimization methods described in this chapter require the use of software and, therefore, no examples are presented here. These methods are useful to generate a prioritized list of independent countermeasure improvement projects at multiple or at one site with mutually exclusive alternatives, based on the decision criteria selected.

8.4.1. The Situation

The highway agency has identified safety countermeasures, benefits, and costs for various improvements at an intersection and segments shown in Table 8-2.

Table 8-1. Summary of Project Prioritization Methods

Method	Input Needs	Outcomes	Considerations
Ranking by Safety-Related Measures	Various; inputs are readily available or derived using the methods presented in Chapter 7, or both.	A ranked list or lists of projects based on various cost or benefit factors, or both.	The prioritization can be improved by using a number of ranking criteria. Not effective for prioritizing many project alternatives or projects across many sites. The list is not necessarily optimized for a given budget.
Benefit Cost Ratio	Present value of monetary benefits and costs for economically justified projects.	A ranked list of independent projects.	Multiple benefit cost ratio calculations. Gives highest return (of monetary benefits) for the budget.
Incremental Benefit Cost Analysis	Present value of monetary benefits and costs for economically justified projects. Spreadsheet and/or a software program.	Selected project from (mutually exclusive) projects based on the benefits they provide and on their cost at a site.	Multiple benefit cost ratio calculations. Spreadsheet or software is useful to automate and track the calculations. Selected projects may vary with different budgets.
Linear Programming (LP)	Present value of monetary benefits and costs for economically justified projects. Spreadsheet or a software program, or both.	An optimized list of projects that provide: 1. Maximum benefits for a given budget, or 2. Minimum cost for a predetermined benefit.	Generally most applicable to roadway projects without defined limits. Microsoft Excel can be used to solve LP problems for a limited set of values. Other computer software packages are available to solve LP problems that have many variables. There are no generally available LP packages specifically customized for highway safety applications.
Integer Programming (IP)	Present value of monetary benefits and costs for economically justified projects. Spreadsheet or software program, or both.	An optimized list of projects that provide: 1. Maximum benefits for a given budget, or 2. Minimum cost for a predetermined benefit.	Generally most applicable to projects with fixed bounds. Microsoft Excel can be used to solve IP problems for a limited set of values. Other computer software packages are available to efficiently solve IP problems. SafetyAnalyst and RSRAP provide IP packages developed specifically for highway safety applications.
Dynamic Programming (DP)	Present value of monetary benefits and costs for economically justified projects. Software program to solve the DP problem.	An optimized list of projects that provide: 1. Maximum benefits for a given budget, or 2. Minimum cost for a predetermined benefit.	Computer software is needed to efficiently solve DP problems.
Multi-Objective Resource Allocation	Present value of monetary benefits and costs for economically justified projects. Software program to solve the multi-objective problem.	A set of projects that optimizes multiple project objectives, including safety and other decision criteria, simultaneously in accordance with user-specified weights for each project objectives.	Computer software is needed to efficiently solve multi-objective problems. User must specify weights for each project objective, including crash reduction measures and other decision criteria.

Table 8-2. Intersections and Roadway Segments Selected for Further Review

					Crash Data		
Intersections	Change in Traffic Control	Major AADT	Minor AADT	Urban/ Rural	Total Year 1	Total Year 1	Total Year 1
2 – Alt 1	TWSC to single lane roundabout	22,100	1,650	U	9	11	15
2 – Alt 2	TWSC –add signal & protect left turn lane	22,100	1,650	U	11	9	14
2 – Alt 3	TWSC – add signal & red light camera	22,100	1,650	U	12	15	11
2 – Alt 4	TWSC – install interchange	22,100	1,650	U	10	14	8

					Crash Data (Total)		
Segments	Cross-Section (# of Lanes)	Segment Length (mi)	AADT	Undivided/ Divided	Year 1	Year 1	Year 1
1	2	0.60	9,000	U	16	15	14
2	2	0.40	15,000	U	12	14	10
5	4	0.35	22,000	U	18	16	15
6	4	0.30	25,000	U	14	12	10
7	4	0.45	26,000	U	12	11	13

Table 8-3 summarizes the countermeasure, benefits, and costs for each of the sites selected for further review. The present value of crash reduction was calculated for Intersection 2, alternative 1, in Chapter 7. Other crash costs represent theoretical values developed to illustrate the sample application of the ranking process for mutually exclusive alternative projects at Intersection 2 and for the independent road segments.

Table 8-3. Summary of Countermeasure, Crash Reduction, and Cost Estimates for Selected Intersection Projects and Roadway Segments

Mutually Exclusive Alternatives			
Intersection	Countermeasure	Present Value of Crash Reduction	Cost Estimate
2 – Alt 1	Single-Lane Roundabout	$4,316,570	$1,500,000
2 – Alt 2	Add Protected Left-Turn Signal	$642,734	$213,195
2 – Alt 3	Install Red Light Cameras	$-379,365	$213,195
2 – Alt 4	Install Interchange	$2,462,175	$15,000,000
Independent Alternatives			
Segments	Countermeasure	Present Value of Safety Benefits	Cost Estimate
1	Shoulder Rumble Strips	$3,517,400	$250,000
2	Shoulder Rumble Strips	$2,936,700	$225,000
5	Convert to Divided	$7,829,600	$3,500,000
6	Convert to Divided	$6,500,000	$2,750,000
7	Convert to Divided	$7,000,000	3,100,000

The Question

Which safety improvement projects would be selected based on ranking the projects by Cost-Effectiveness, Net Present Value (NPV), and Benefit cost Ratio (BCR) measures? Recall, the cost-effectiveness measure ranks based on the number of crashes, and does not take account of their severity or a limited budget. The NPV and BCR measures consider the severity of crashes, however the NPV method only yields an optimal ranking for a budget if the projects costs are equal.

The Facts

Table 8-4 summarizes the crash reduction, monetary benefits and costs for the safety improvement projects being considered.

Table 8-4. Project Facts

Location	Estimated Average Reduction in Crash Frequency	Present Value of Crash Reduction	Cost Estimate
Mutually Exclusive Projects			
Intersection 2 – Alt 1	47	$4,316,570	$1,500,000
Intersection 2 – Alt 2	6	$642,734	$213,195
Intersection 2 – Alt 3	7	$-379,365	$213,195
Intersection 2 – Alt 4	9	$2,462,175	$15,000,000
Independent Projects			
Segment 1	18	$3,517,400	$250,000
Segment 2	16	$2,936,700	$225,000
Segment 5	458	$7,829,600	$3,500,000
Segment 6	110	$6,500,000	$2,750,000
Segment 7	120	$7,000,000	$3,100,000

Solution

The evaluation and prioritization of intersection alternatives and roadway-segment projects are both presented in this set of examples. The method to rank multiple countermeasures at a single intersection or segment is demonstrated in the sample problem using the IBCR.

Simple Ranking—Cost-Effectiveness

The ranking of the total cost of projects versus total crashes reduced. This does not provide the optimal ranking for a given budget and does not treat the relative severity of the crash experience.

Step 1—Estimate Crash Reduction

Divide the cost of the project by the total estimated crash reduction as shown in Equation 8-2.

$$\text{Cost-Effectiveness} = \text{Cost of the project/Total crashes reduced} \qquad \textbf{(Eq. 8-2)}$$

Table 8-5 summarizes the results of this method.

Table 8-5. Cost-Effectiveness Evaluation

Project	Total Reduction in Crash Frequency	Cost	Cost Effectiveness (Cost/Crash Reduced)
Mutually Exclusive Projects			
Intersection 2 – Alt 1	47	$1,500,000	$31,915
Intersection 2 – Alt 2	6	$213,195	$35,533
Intersection 2 – Alt 3	7	$213,195	$30,457
Intersection 2 – Alt 4	9	$15,000,000	$1,666,667
Independent Projects			
Segment 1	18	$250,000	$13,889
Segment 2	16	$225,000	$14,063
Segment 5	458	$3,500,000	$7,642
Segment 6	110	$2,750,000	$25,000
Segment 7	120	$3,100,000	$25,833

Step 2—Rank Projects by Cost-Effectiveness

The improvement project with the lowest cost-effective value is the most cost-effective at reducing crashes. Table 8-6 shows the countermeasure implementation projects listed based on simple cost-effectiveness ranking. This ranking does not take account of the economic use of a given budget or relative severity of the crashes.

Table 8-6. Cost-Effectiveness Ranking

Project	Cost Effectiveness*
Segment 5	$7,642
Segment 1	$13,889
Segment 2	$14,063
Segment 6	$25,000
Segment 7	$25,833
Intersection 2, Alt 3	$30,457
Intersection 2, Alt 1	$31,915
Intersection 2, Alt 2	$35,533
Intersection 2, Alt 4	$1,666,667

* Cost-Effectiveness = cost of project / total crashes reduced

Simple Ranking – Net Present Value (NPV)

The net present value (NPV) method is also referred to as the net present worth (NPW) method. This method is used to express the difference between discounted benefits and discounted costs of an individual improvement projects in a single amount. This method does not give an optimal ranking with a limited budget, unless individual project costs are equal.

Step 1—Calculate the NPV

Subtract the cost of the project from the benefits as shown in Equation 8-3;

$$NPV = \text{Present Monetary Value of the Benefits} - \text{Present Cost of the project} \quad \textbf{(Eq. 8-3)}$$

Step 2 – Rank Sites Based on NPV

Rank sites based on the NPV as shown in Table 8-7.

Table 8-7. Net Present Value Results

Mutually Exclusive Projects			
Project	Present Value of Benefits ($) (PVB)	Project Cost ($) (PVC)	Net Present Value ($) (NPV)
Intersection 2 – Alt 1	$4,316,570	$1,500,000	$2,816,570
Intersection 2 – Alt 2	$642,734	$213,195	$429,539
Intersection 2 – Alt 3	$-379,365	$213,195	$-592,560
Intersection 2 – Alt 4	$2,462,175	$15,000,000	$-12,537,825
Independent Projects			
Segment 1	$3,517,400	$250,000	$3,267,400
Segment 2	$2,936,700	$225,000	$2,711,700
Segment 5	$7,829,600	$3,500,000	$4,329,600
Segment 6	$6,500,000	$2,750,000	$3,750,000
Segment 7	$7,000,000	$3,100,000	$3,900,000

As shown in Table 8-7, Segment 5 has the highest net present value of $4,329,500 out of the intersection and roadway segment projects being considered.

All but two of the improvement projects have net present values greater than zero, indicating they are economically feasible projects because the monetary benefit is greater than the cost. Intersection 2, alternatives 3 and 4, have net present values less than zero, indicating that the calculated monetary benefits do not outweigh the cost of the project. The highway agency may consider additional benefits (both monetary and non-monetary) that may be brought about by the projects before implementing them.

This ranking does not provide an optimal set of projects for a given budget since only two projects have equal project costs, alternatives 2 and 3 for Intersection 2. Although Alt 2 and Alt 3 can be compared with each other, the other mutually exclusive projects cannot be compared for effective use of the budget.

Table 8-8. Net Present Value (NPV) Ranking

Project	NPV	NPV Rank
Segment 5	$4,329,600	1
Segment 7	$3,900,000	2
Segment 6	$3,750,000	3
Segment 1	$3,267,400	4
Intersection 2, Alt 1	$2,816,570	5
Segment 2	$2,711,700	6
Intersection 2, Alt 2	$429,539	7

Note: Alternatives 3 and 4, Intersection 2, have negative NPV values and are not ranked

The net present values (NPV) do not provide an interesting comparison of benefits and costs, however this ranking cannot be used to select an optimal set of projects within a given budget, unless project costs are equal.

Simple Ranking—Benefit Cost Ratio (BCR)

This method uses the ratios between discounted benefits and discounted costs of individual independent improvement projects. Independent projects, typically at separate sites, are best ranked using the benefit cost ratio (BCR). This ranking can be used to achieve optimal use of a given budget.

Step 1—Calculate the BCR

Divide the benefits for a project by its cost to obtain the BCR, as shown in Equation 8-4.

$$BCR = \text{Present Monetary Value of the Benefits / Cost of the Project} \qquad \textbf{(Eq. 8-4)}$$

Section 7.6.1.2 illustrates the process for calculating the BCR for each project.

Step 2—Rank Sites Based on BCR

Rank sites based on the BCR as shown in Table 8-9.

Table 8-9. Ranking Independent Projects by Benefit Cost Ratio

Project	Present Value of Benefits ($) (PVB)	Cost of Improvement Project ($) (PVC)	Benefit/Cost (BCR)	BCR Rank	(NPV Rank)*
Segment 1	$3,517,400	$250,000	14.1	1	(4)
Segment 2	$2,936,700	$225,000	13.1	2	(6)
Segment 5	$7,829,600	$3,500,000	2.24	5	(1)
Segment 6	$6,500,000	$2,750,000	2.36	3	(3)
Segment 7	$7,000,000	$3,100,000	2.26	4	(2)

* NPV Rank shown for comparison with BCR rank

Using Equation 8-4, the BCRs for the projects are calculated. For example, for Segment 1;

$$\text{BCR} = \frac{\text{PVB}_1}{\text{PVC}_1} = \frac{\$3{,}517{,}400}{\$250{,}000} = 14.1$$

As shown in Table 8-9, Segment 1 has the highest benefit cost ratio out of the independent roadway segment projects being considered, i.e., 14.1, so it is ranked “1.” A comparison of the rank order by the BCR versus the NPV in the last two columns of Table 8-9 shows very different rankings. The BCR ranking is optimal for a limited budget. The mutually exclusive projects at Intersection 2 are not ranked by the BCR method. They should be ranked by the IBCR method.

All of the improvement projects have positive benefit cost ratios greater than “1”, indicating they are economically feasible projects because the monetary benefit is greater than the cost. It is possible to have projects with BCR less than one, indicating that the calculated monetary benefits do not outweigh the cost of the project. The highway agency may consider additional benefits (both monetary and non-monetary) that may be brought about by the projects before implementing them.

A set of projects can be selected to give optimal use of a limited budget based on these rankings. Each of the projects are selected in rank order as long as there are sufficient budgeted funds.

Ranking by Incremental Benefit cost Analysis (IBCR)

Incremental benefit cost analysis is an extension of the benefit cost ratio (BCR) method presented in Chapter 7. However, it cannot be applied to the above example because all projects are independent. It is applied where the selection of one alternative project precludes the use of any other alternatives, i.e., mutually exclusive alternatives.

Step 1—Calculate the BCR

Section 7.6.1.2 illustrates the process for calculating the BCR for each project.

Step 2—Organize Projects by Project Cost

The projects are ordered by project cost, as shown in Table 8-10.

Table 8-10. Benefits and Costs for Mutually Exclusive Alternative Projects for Intersection 2 ordered by Cost of Project

Project	Present Value of Benefits (PVB)	Present Value of Cost (PVC)	Benefit Cost Ratio (BCR)
Intersection 2 – Alt 3	$-379,365	$213,195	-1.8
Intersection 2 – Alt 2	$642,734	$213,195	3.0
Intersection 2 – Alt 1	$4,316,570	$1,500,000	2.9
Intersection 2 – Alt 4	$2,462,175	$15,000,000	.16

Step 3—Calculate Incremental BCR (IBCR)

Equation 8-5 is applied to a series of project pairs ordered by project cost. If the incremental BCR is greater than 1.0, the higher-cost project is preferred to the lower cost project. If the incremental BCR is a positive value less than 1.0, or is zero or negative, the lower-cost project is preferred to the higher cost project. The computations then proceed comparing the preferred project from the first comparison to the project with the next highest cost. The preferred alternative from the final comparison is assigned the highest priority.

$$\textit{Incremental BCR} = (PV_{\text{benefits 2}} - PV_{\text{benefits 1}}) / (PV_{\text{costs 2}} - PV_{\text{costs 1}}) \qquad \textbf{(Eq. 8-5)}$$

where:

$PV_{\text{benefits 1}}$ = Present value of benefits for lower-cost project

$PV_{\text{benefits 2}}$ = Present value of benefits for higher-cost project

$PV_{\text{costs 1}}$ = Present value of cost for lower-cost project

$PV_{\text{costs 2}}$ = Present value of cost for higher-cost project

Table 8-11 illustrates the sequence of incremental benefit cost comparisons needed to assign priority to the projects.

Table 8-11. Incremental BCR Results for a Set of Mutually Exclusive Projects

Project	Present Value of Benefits (PVB)	Present Value of Cost (PVC)	Benefit Cost Ratio (BCR) (Step 1)	IBCR$_1$ (Step 2)	IBCR$_2$ (Step 3)	Selected Project
Intersection 2 – Alt 3	$-379,365	$213,195	-1.8	--	--	--
	(Alt 3 dropped with negative BCR)					
Intersection 2 – Alt 2	$642,734	$213,195	3.01			~~Alt 2~~
{A1-A2}	ΔPVB = $3,673,836	ΔPVC = $1,286,805		2.86 > 1		Alt 1 replaces Alt 2
Intersection 2 – Alt 1	$4,316,570	$1,500,000	2.88			
{A4-A2}	ΔPVB = -$1,819,441	ΔPVC = $14,786,805		-0.12		
{A4-A1}	ΔPVB = -$1,854,395	ΔPVC = $13,500,000			-0.14	No
Intersection 2 – Alt 4	$2,462,175	$15,000,000	0.16			

Steps:

1. The projects are sorted in terms of increasing project cost initially, and the first project with a BCR > 1.0, i.e., Alt 2, is selected.
2. Then, the incremental benefits are divided by the incremental costs for each pair beginning with the lowest cost pair, that is, the IBCR for Alt 1 over Alt 2 is;

$$\mathrm{IBCR}_{1-2} = \frac{\Delta \mathrm{PVB}_{1-2}}{\Delta \mathrm{PVC}_{1-2}} = \frac{\$3{,}673{,}836}{\$1{,}286{,}805} = 2.86$$

   When A2 is compared to the next higher cost project Alt 1, it gives an IBCR = 2.86, so it would be selected over Alt 2. Alt 2 would be dropped from the ranking since it is a mutually exclusive project.

3. Comparing the incremental benefits of Alt 4 to Alt 1 yields a negative IBCR, that is;

$$\mathrm{IBCR}_{4-1} = \frac{\Delta \mathrm{PVB}_{4-1}}{\Delta \mathrm{PVC}_{4-1}} = \frac{\$-1{,}854{,}395}{\$13{,}500{,}000} = -0.14$$

   So, Alt 4 would not be selected.

Note: Since these are mutually exclusive alternatives, only one project is selected. All other projects are precluded by the selection of Alternative 1.

Comments

The ranking of the projects by benefit cost analysis differs from the project rankings obtained with cost effectiveness and the present value computations. Benefit cost analysis develops an economically optimal set of ranked independent projects. Incremental benefit cost analysis provides greater insight into whether the expenditure represented by each increment of additional cost is economically justified for mutually exclusive projects. Incremental benefit cost analysis provides insight into the priority ranking of alternative projects, and also lends itself to incorporating a formal budget constraint.

References

1. Chowdhury, M.A., N.J. Garber, and D. Li. Multi-objective Methodology for Highway Safety Resource Allocation. *Journal of Infrastructure Systems*, Vol. 6, No. 4. American Society of Civil Engineers, Reston, VA, 2000.

2. Harwood, D.W., E.R. Kohlman Rabbani, K.R. Richard, H.W. McGee, and G.L. Gittings. *National Cooperative Research Program Report 486: Systemwide Impact of Safety and Traffic Operations Design Decisions for 3R Projects*. NCHRP, Transportation Research Board, Washington, DC, 2003.

3. Mak, K.K., and D.L. Sicking. *National Cooperative Research Program Report 492: Roadside Safety Analysis Program.* NCHRP, Transportation Research Board, Washington, DC, 2003.

4. Roop, S.S., and S.K. Mathur. *Development of a Multimodal Framework for Freight Transportation Investment: Consideration of Rail and Highway Tradeoffs*. Final Report of NCHRP Project 20-29. Texas A&M University, College Station, TX, 1995.

5. Grant, Eugene L., Ireson, W. Grant, and Richard S. Leavenworth. *Principles of Engineering Economy*. New York: John Wiley and Sons, 1990, 591 pp.

6. Riggs, James L., *Engineering Economics*. New York: McGraw-Hill, 1982, 789 pp.

7. Steiner, Henry Malcolm, *Engineering Economic Principles*. New York: McGraw-Hill, 1992, 559 pp.

8. Park, C.S., and G.P. Sharp-Batte. *Advanced Engineering Economics*. New York: Wiley, 1990.