PART B — ROADWAY SAFETY MANAGEMENT PROCESS

CHAPTER 7—ECONOMIC APPRAISAL

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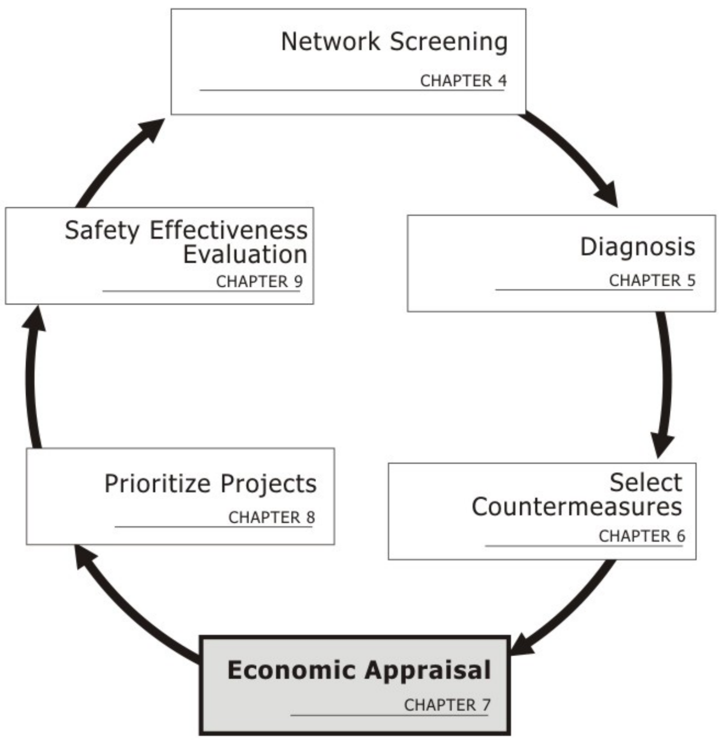
CHAPTER 7 ECONOMIC APPRAISAL

7.1. INTRODUCTION

Economic appraisals are performed to compare the benefits of potential crash countermeasure to its project costs. Site economic appraisals are conducted after the highway network is screened (*Chapter 4*), the selected sites are diagnosed (*Chapter 5*), and potential countermeasures for reducing crash frequency or crash severity are selected (*Chapter 6*). Exhibit 7-1 shows this step in the context of the overall roadway safety management process.

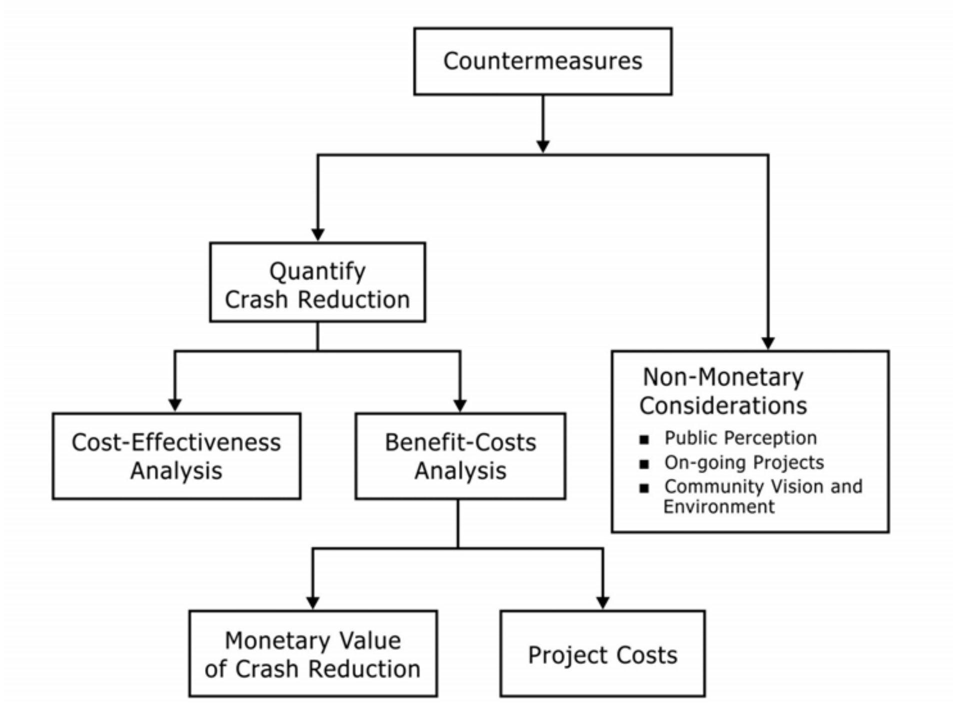
Exhibit 7-1: Roadway Safety Management Process Overview

Economic appraisals are used to estimate the monetary benefit of safety improvements.



In an economic appraisal, project costs are addressed in monetary terms. Two types of economic appraisal – benefit-cost analysis and cost-effectiveness analysis – address project benefits in different ways. Both types begin quantifying the benefits of a proposed project, expressed as the estimated change in crash frequency or severity of crashes, as a result of implementing a countermeasure. In benefit-cost analysis, the expected change in average crash frequency or severity is converted to monetary values, summed, and compared to the cost of implementing the countermeasure. In cost-effectiveness analysis, the change in crash frequency is compared directly to the cost of implementing the countermeasure. This chapter also presents methods for estimating benefits if the expected change in crashes is unknown. Exhibit 7-2 provides a schematic of the economic appraisal process.

Exhibit 7-2: Economic Appraisal Process



As an outcome of the economic appraisal process, the countermeasures for a given site can be organized in descending or ascending order by the following characteristics:

- Project costs
- 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
- Net Present Value (NPV)
- Benefit-Cost Ratio (BCR)
- Cost-Effectiveness Index

Ranking alternatives for a given site by these characteristics can assist highway agencies in selecting the most appropriate alternative for implementation.

7.2. OVERVIEW OF PROJECT BENEFITS AND COSTS

In addition to project benefits associated with a change in crash frequency, project benefits such as travel time, environmental impacts, and congestion relief are also considerations in project evaluation. However, the project benefits discussed in *Chapter 7* relate only to changes in crash frequency. Guidance for considering other project benefits, such as travel-time savings and reduced fuel consumption, are found in the American Association of State Highway and Transportation Officials (AASHTO) publication entitled *A Manual of User Benefit Analysis for Highways* (also known as the AASHTO Redbook).[1]

The HSM predictive method presented in *Part C* provides a reliable method for estimating the change in expected average crash frequency due to a countermeasure. After applying the *Part C* predictive method to determine expected average crash frequency for existing conditions and proposed alternatives, the expected change in average fatal and injury crash frequency is converted to a monetary value using the societal cost of crashes. Similarly, the expected change in property damage only (PDO) crashes (change in total crashes minus the change in fatal and injury crashes) is converted to a monetary value using the societal cost of a PDO collision. Additional methods for estimating a change in crash frequency are also described in this chapter, although it is important to recognize the results of those methods are not expected to be as accurate as the *Part C* predictive method.

Part C presents methods to estimate a change in the average crash frequency at a site.

7.3. DATA NEEDS

The data needed to calculate the change in crash frequency and countermeasure implementation costs are summarized in Exhibit 7-3. Appendix A includes a detailed explanation of the data needs.

Exhibit 7-3: Data Needs for Calculating Project Benefits

Activity	Data Need
Calculate Monetary Benefit	
Estimate change in crashes by severity	Crash history by severity
	Current and future Average Annual Daily Traffic (AADT) volumes
	Implementation year for expected countermeasure
	SPF for current and future site conditions (if necessary)
	AMFs for all countermeasures under consideration
Convert change in crash frequency to annual monetary value	Monetary value of crashes by severity
	Change in crash frequency estimates
Convert annual monetary value to a present value	Service life of the countermeasure
	Discount rate (minimum rate of return)
Calculate Costs	
Calculate construction and other implementation costs	Subject to standards for the jurisdiction
Convert costs to present value	Service life of the countermeasure(s)
	Project phasing schedule

7.4. ASSESS EXPECTED PROJECT BENEFITS

This section outlines the methods for estimating the benefits of a proposed project based on the estimated change in average crash frequency. The method used will depend on the facility type and countermeasures, and the amount of research that has been conducted on such facilities and countermeasures. The HSM's suggested method for determining project benefits is to apply the predictive method presented in *Part C.*

Section 7.4.1 reviews the applicable methods for estimating a change in average crash frequency for a proposed project. The discussion in Section 7.4.1 is consistent with the guidance provided in the *Part C Introduction and Applications Guidance.* Section 7.4.2 describes how to estimate the change in expected average crash frequency when none of the methods outlined in Section 7.4.1 can be applied. Section 7.4.3 describes how to convert the expected change in average crash frequency into a monetary value.

7.4.1. Estimating Change in Crashes for a Proposed Project

The Part C Introduction and Applications Guidance provides detailed information about the HSM predictive method, SPFs, and AMFs.

The *Part C Predictive Method* provides procedures to estimate the expected average crash frequency when geometric design and traffic control features are specified. This section provides four methods, in order of reliability for estimating the change in expected average crash frequency of a proposed project or project design alterative. These are:

- Method 1 – Apply the *Part C* predictive method to estimate the expected average crash frequency of both the existing and proposed conditions.
- Method 2 – Apply the *Part C* predictive method to estimate the expected average crash frequency of the existing condition and apply an appropriate project AMF from *Part D* to estimate the safety performance of the proposed condition.
- Method 3 – If the *Part C* predictive method is not available, but a Safety Performance Function (SPF) applicable to the existing roadway condition is available (i.e., a SPF developed for a facility type that is not included in *Part C*), use that SPF to estimate the expected average crash frequency of the existing condition and apply an appropriate project AMF from *Part D* to estimate the expected average crash frequency of the proposed condition. A locally-derived project AMF can also be used in Method 3.
- Method 4 – Use observed crash frequency to estimate the expected average crash frequency of the existing condition, and apply an appropriate project AMF from *Part D* to the estimated expected average crash frequency of the existing condition to obtain the estimated expected average crash frequency for the proposed condition. This method is applied to facility types with existing conditions not addressed by the *Part C* predictive method.

When an AMF from *Part D* is used in one of the four methods, the associated standard error of the AMF can be applied to develop a confidence interval around the expected average crash frequency estimate. The range will help to see what type of variation could be expected when implementing a countermeasure.

7.4.2. Estimating a Change in Crashes When No Safety Prediction Methodology or AMF is Available

Section 7.4.1 explains that estimating the expected change in crashes for a countermeasure can be accomplished with the *Part C* predictive method, the *Part D* AMFs, or with locally developed AMFs. When there is no applicable *Part C* predictive method, no applicable SPF, and no applicable AMF, the HSM procedures cannot provide an estimate of the expected project effectiveness.

In order to evaluate countermeasures when no valid AMF is available, an estimate of the applicable AMF may be chosen using engineering judgment. The results of such analysis are considered uncertain and a sensitivity analysis based on a range of AMF estimates could support decision making.

7.4.3. Converting Benefits to a Monetary Value

Converting the estimated change in crash frequency to a monetary value is relatively simple as long as established societal crash costs by severity are available. First the estimated change in crash frequency is converted to an annual monetary value. This annual monetary value may or may not be uniform over the service life of the project. Therefore, in order to obtain a consistent unit for comparison between sites, the annual value is converted to a present value.

7.4.3.1. Calculate Annual Monetary Value

The following data is needed to calculate annual monetary value:

- Accepted monetary value of crashes by severity
- Change in crash estimates for:
  - Total Crashes
  - Fatal/Injury Crashes
  - PDO Crashes

In order to develop an annual monetary value the societal cost associated with each crash severity is multiplied by the corresponding annual estimate of the change in crash frequency. State and local jurisdictions often have accepted crash costs by crash severity and collision type. When available, these locally-developed crash cost data are used with procedures in the HSM. If local information is not available, nationwide crash cost data is available from the Federal Highway Administration (FHWA). This edition of the HSM applies crash costs from the FHWA report *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries*.[(2)] The costs cited in this 2005 report are presented in 2001 dollars. The *Chapter 4* appendix includes a summary of a procedure for updating annual monetary values to current year values. Exhibit 7-4 summarizes the relevant information for use in the HSM (rounded to the nearest hundred dollars).

The Chapter 4, *Appendix A* includes a summary of the recommended procedure for updating annual monetary values to current year values.

Exhibit 7-4: Crash Cost Estimates by Crash Severity

Collision Type	Comprehensive Crash Costs
Fatality (K)	$4,008,900
Disabling Injury (A)	$216,000
Evident Injury (B)	$79,000
Fatal/Injury (K/A/B)	$158,200
Possible Injury (C)	$44,900
PDO (O)	$7,400

Source: Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries, FHWA - HRT - 05-051, October 2005.

Because SPFs and AMFs do not always differentiate between a fatal and injury crashes when estimating average crash frequencies, many jurisdictions have established a societal cost that is representative of a combined fatal/injury crash. The value determined by FHWA is shown in *Exhibit 7-4* as $158,200.

> A countermeasure is estimated to reduce the expected average crash frequency of fatal/injury crashes by five crashes per year and the number of PDO crashes by 11 per year over the service year of the project. What is the annual monetary benefit associated with the crash reduction?
>
> Fatal/Injury Crashes: 5 x $158,200 = $791,000/year
>
> PDO crashes: 11 x $7,400 = $81,400/year
>
> Total Annual Monetary Benefit: $791,000+$81,400 = $872,400/year

7.4.3.2. Convert Annual Monetary Value to Present Value

This section describes the method to calculate present value of monetary benefits.

There are two methods that can be used to convert annual monetary benefits to present value. The first is used when the annual benefits are uniform over the service life of the project. The second is used when the annual benefits vary over the service life of the project.

The following data is needed to convert annual monetary value to present value:

- Annual monetary benefit associated with the change in crash frequency (as calculated above);
- Service life of the countermeasure(s); and,
- Discount rate (minimum rate of return).

7.4.3.3. Method One: Convert Uniform Annual Benefits to a Present Value

When the annual benefits are uniform over the service life of the project Equations 7-1 and 7-2 can be used to calculate present value of project benefits.

$$PV_{benefits} = TotalAnnualMonetaryBenefits \times (P/A,\ i,\ y) \tag{7-1}$$

Where,

$PV_{benefits}$ = Present value of the project benefits for a specific site, v

$(P/A, i, y)$ = Conversion factor for a series of uniform annual amounts to present value

$$(P/A, i, y) = \frac{(1.0 + i)^{(y)} - 1.0}{i \times (1.0 + i)^{(y)}} \tag{7-2}$$

i = Minimum attractive rate of return or discount rate (i.e., if the discount rate is 4%, the i = 0.04)

y = Year in the service life of the countermeasure(s)

From the previous example, the total annual monetary benefit of a countermeasure is $872,400. What is the present value of the project?

Applying Equation 7-2:

Assume,

i = 0.04

y = 5 years

Then,

$$(P/A, i, y) = \frac{(1.0 + 0.04)^{(5)} - 1.0}{0.04 \times (1.0 + 0.04)^{(5)}} = 4.45$$

Applying Equation 7-1:

$PV_{benefits}$ = $872,400 x (4.45)

= $3,882,180

7.4.3.4. Method Two: Convert Non-Uniform Annual Benefits to Present Value

Some countermeasures yield larger changes in expected average crash frequency in the first years after implementation than in subsequent years. In order to account for this occurrence over the service life of the countermeasure, non-uniform annual monetary values can be calculated as shown in Step 1 below for each year of service. The following process is used to convert the project benefits of all non-uniform annual monetary values to a single present value:

1. Convert each annual monetary value to its individual present value. Each future annual value is treated as a single future value; therefore, a different present worth factor is applied to each year.
    a) Substitute the (P/F, i, y) factor calculated for each year in the service life for the (P/A, i, y) factor presented in Equation 7-2.
        i) (P/F, i, y) = a factor that converts a single future value to its present value
        ii) (P/F, i, y) = $(1+i)^{(-y)}$

        Where,

        i = discount rate (i.e., the discount rate is 4%, i = 0.04)

        y = year in the service life of the countermeasure(s)
2. Sum the individual present values to arrive at a single present value that represents the project benefits of the project.

The sample problems at the end of this chapter illustrate how to convert non-uniform annual values to a single present value.

7.5. ESTIMATE PROJECT COSTS

Estimating the cost associated with implementing a countermeasure follows the same procedure as performing cost estimates for other construction or program implementation projects. Similar to other roadway improvement projects, expected project costs are unique to each site and to each proposed countermeasure(s). The cost of implementing a countermeasure or set of countermeasures could include a variety of factors. These may include right-of-way acquisition, construction material costs, grading and earthwork, utility relocation, environmental impacts, maintenance, and other costs including any planning and engineering design work conducted prior to construction.

The *AASHTO Redbook* states "Project costs should include the present value of any obligation to incur costs (or commit to incur costs in the future) that burden the [highway] authority's funds."[(1)] Therefore, under this definition the present value of construction, operating, and maintenance costs over the service life of the project are included in the assessment of expected project costs. *Chapter 6* of the *AASHTO Redbook* provides additional guidance regarding the categories of costs and their proper treatment in a benefit-cost or economic appraisal. Categories discussed in the Redbook include:

- Construction and other development costs
- Adjusting development and operating cost estimates for inflation
- The cost of right-of-way
- Measuring the current and future value of undeveloped land
- Measuring current and future value of developed land
- Valuing already-owned right-of-way
- Maintenance and operating costs
- Creating operating cost estimates

Project costs are expressed as present values for use in economic evaluation. Project construction or implementation costs are typically already present values, but any annual or future costs need to be converted to present values using the same relationships presented for project benefits in Section 7.4.3.

7.6. ECONOMIC EVALUATION METHODS FOR INDIVIDUAL SITES

There are two main objectives for the economic evaluation of a countermeasure or combination of countermeasures:

The two main objectives for economic evaluation are to determine:
1) if a project is economically justified, and
2) which project is most cost-effective.

1. Determine if a project is economically justified (i.e., the benefits are greater than the costs), and
2. Determine which project or alternative is most cost-effective.

Two methods are presented in Section 7.6.1 that can be used to conduct cost-benefit analysis in order to satisfy the first objective. A separate method is described in Section 7.6.2 that can be used to satisfy the second objective. A step-by-step process for using each of these methods is provided, along with an outline of the strengths and limitations of each.

In situations where an economic evaluation is used to compare multiple alternative countermeasures or projects at a single site, the methods presented in *Chapter 8* for evaluation of multiple sites can be applied.

7.6.1. Procedures for Benefit-Cost Analysis

Section 7.6.1 provides a description of the methods to calculate net present value (NPV) and benefit-cost ratio (BCR).

Net present value and benefit-cost ratio are presented in this section. These methods are commonly used to evaluate the economic effectiveness and feasibility of individual roadway projects. They are presented in this section as a means to evaluate countermeasure implementation projects intended to reduce the expected average crash frequency or crash severity. The methods utilize the benefits calculated in Section 7.4 and costs calculated in Section 7.5. The FHWA SafetyAnalyst software provides an economic-appraisal tool that can apply each of the methods described below.(3)

7.6.1.1. 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 costs and discounted benefits of an individual improvement project in a single amount. The term "discount" indicates that the monetary costs and benefits are converted to a present value using a discount rate.

Applications

The NPV method is used for the two basic functions listed below:

- Determine which countermeasure or set of countermeasures provides the most cost-efficient means to reduce crashes. Countermeasure(s) are ordered from the highest to lowest NPV.
- Evaluate if an individual project is economically justified. A project with a NPV greater than zero indicates a project with benefits that are sufficient enough to justify implementation of the countermeasure.

Method

1. Estimate the number of crashes reduced due to the safety improvement project (see Section 7.4 and the *Part C Introduction and Applications Guidance*).
2. Convert the change in estimated average crash frequency to an annual monetary value to representative of the benefits (see Section 7.5).
3. Convert the annual monetary value of the benefits to a present value (see Section 7.5).
4. Calculate the present value of the costs associated with implementing the project (see Section 7.5).
5. Calculate the NPV using Equation 7-3:

$$NPV = PV_{benefits} - PV_{costs} \quad (7\text{-}3)$$

Where,

$PV_{benefits}$ = Present value of project benefits

PV_{costs} = Present value of project costs

6. If the NPV > 0, then the individual project is economically justified.

Exhibit 7-5 presents the strengths and limitations of NPV Analysis.

Exhibit 7-5: Strengths and Limitations of NPV Analysis

Strengths	Weaknesses
• This method evaluates the economic justification of a project.	• The magnitude cannot be as easily interpreted as a benefit-cost ratio.
• NPV are ordered from highest to lowest value.	
• It ranks projects with the same rankings as produced by the incremental-benefit-to-cost-ratio method discussed in Chapter 8.	

7.6.1.2. Benefit-Cost Ratio (BCR)

A benefit-cost ratio is the ratio of the present-value benefits of a project to the implementation costs of the project (BCR = Benefits/Costs). If the ratio is greater than 1.0, then the project is considered economically justified. Countermeasures are ranked from highest to lowest BCR. An incremental benefit-cost analysis (*Chapter 8*) is needed to use the BCR as a tool for comparing project alternatives.

Applications

This method is used to determine the most valuable countermeasure(s) for a specific site and is used to evaluate economic justification of individual projects. The benefit-cost ratio method is not valid for prioritizing multiple projects or multiple alternatives for a single project; the methods discussed in *Chapter 8* are valid processes to prioritize multiple projects or multiple alternatives.

Method

1. Calculate the present value of the estimated change in average crash frequency (see *Section 7.5*).
2. Calculate the present value of the costs associated with the safety improvement project (see *Section 7.5*).
3. Calculate the benefit-cost ratio by dividing the estimated project benefits by the estimated project costs.

$$BCR = \frac{PV_{benefits}}{PV_{costs}} \quad (7\text{-}4)$$

Where,

BCR = Benefit cost ratio

$PV_{benefits}$ = Present value of project benefits

PV_{costs} = Present value of project costs

4. If the BCR is greater than 1.0, then the project is economically justified.

Exhibit 7-6 presents the strengths and limitations of BCR Analysis.

Exhibit 7-6: Strengths and Limitations of BCR Analysis

Strengths	Weaknesses
• The magnitude of the benefit-cost ratio makes the relative desirability of a proposed project immediately evident to decision makers.	• Benefit-cost ratio cannot be directly used in decision making between project alternatives or to compare projects at multiple sites. An incremental benefit-cost analysis would need to be conducted for this purpose (see *Chapter 8*).
• This method can be used by highway agencies in evaluations for the Federal Highway Administration (FHWA) to justify improvements funded through the Highway Safety Improvement Program (HSIP). Projects identified as economically justified (BCR > 1.0) are eligible for federal funding; however, there are instances where implementing a project with a BCR < 1.0 is warranted based on the potential for crashes without the project.	• This method considers projects individually and does not provide guidance for identifying the most cost-effective mix of projects given a specific budget.

7.6.2. Procedures for Cost-Effectiveness Analysis

In cost-effectiveness analysis the predicted change in average crash frequency are not quantified as monetary values, but are compared directly to project costs.

The cost-effectiveness of a countermeasure implementation project is expressed as the annual cost per crash reduced. Both the project cost and the estimated average crash frequency reduced must apply to the same time period, either on an annual basis or over the entire life of the project. This method requires an estimate of the change in crashes and cost estimate associated with implementing the countermeasure. However, the change in estimated crash frequency is not converted to a monetary value.

Cost effectiveness is the annual cost per crash reduced. The lower the cost per crash reduced, the more effective the treatment.

Applications

This method is used to gain a quantifiable understanding of the value of implementing an individual countermeasure or multiple countermeasures at an individual site when an agency does not support the monetary crash cost values used to convert a project's change in estimated average crash frequency reduction to a monetary value.

Method

1. Estimate the change in expected average crash frequency due to the safety improvement project (see Section 7.4 and the *Part C Introduction and Applications Guidance,* Section C.7).
2. Calculate the costs associated with implementing the project (see Section 7.5).
3. Calculate the cost-effectiveness of the safety improvement project at the site by dividing the present value of the costs by the estimated change in average crash frequency over the life of the countermeasure:

$$Cost\text{ - }Effectiveness\ Index = \frac{PV_{costs}}{N_{predicted}\text{ - }N_{observed}} \quad (7\text{-}5)$$

Where,

PV_{costs} = Present Value of Project Cost

$N_{predicted}$ = Predicted crash frequency for year y

$N_{observed}$ = Observed crash frequency for year y

Exhibit 7-7 presents the strengths and limitations of NPV Analysis.

Exhibit 7-7: Strengths and Limitations of Cost-Effectiveness Analysis

Strengths	Weaknesses
• This method results in a simple and quick calculation that provides a general sense of an individual project's value.	• It does not differentiate between the value of reducing a fatal crash, an injury crash and a PDO crash.
• It produces a numeric value that can be compared to other safety improvement projects evaluated with the same method.	• It does not indicate whether an improvement project is economically justified because the benefits are not expressed in monetary terms.
• There is no need to convert the change in expected average crash frequency by severity or type to a monetary value.	

Section 7.7 describes that non-monetary factors can also be a consideration in project decisions.

7.7. NON-MONETARY CONSIDERATIONS

In most cases, the primary benefits of countermeasure implementation projects can be estimated in terms of the change average crash frequency and injuries avoided and/or monetary values. However, many factors not directly related to changes in crash frequency enter into decisions about countermeasure implementation projects and many cannot be quantified in monetary terms. Non-monetary considerations include:

- Public demand;
- Public perception and acceptance of safety improvement projects;
- Meeting established and community-endorsed policies to improve mobility or accessibility along a corridor;
- Air quality, noise, and other environmental considerations;
- Road user needs; and,
- Providing a context sensitive solution that is consistent with a community's vision and environment.

For example, a roundabout typically provides both quantifiable and non-quantifiable benefits for a community. Quantifiable benefits often include reducing the average delay experienced by motorists, reducing vehicle fuel consumption, and reducing severe angle and head-on injury crashes at the intersection. Each could be converted into a monetary value in order to calculate costs and benefits.

Examples of potential benefits associated with implementation of a roundabout that cannot be quantified or given a monetary value could include:

- Improving aesthetics compared to other intersection traffic control devices;
- Establishing a physical character change that denotes entry to a community (a gateway treatment) or change in roadway functional classification;
- Facilitating economic redevelopment of an area;
- Serving as an access management tool where the splitter islands remove the turbulence of full access driveways by replacing them with right-in/right-out driveways to land uses; and,
- Accommodating U-turns more easily at roundabouts.

For projects intended primarily to reduce crash frequency or severity, a benefit-cost analysis in monetary terms may serve as the primary decision making tool, with secondary consideration of qualitative factors. The decision-making process on larger-scale projects that do not only focus on change in crash frequency may be primarily qualitative, or may be quantitative by applying weighting factors to specific decision criteria such as safety, traffic operations, air quality, noise, etc. *Chapter 8* discusses the application of multi-objective resource allocation tools as one method to make such decisions as quantitative as possible.

7.8. CONCLUSIONS

Chapter 7 provides an overview of methods to estimate the benefits of a countermeasure in terms of a reduction in crash frequency. It also provides methods for comparing the benefits to the costs.

The information presented in this chapter can be used to objectively evaluate countermeasure implementation projects by quantifying the monetary value of each project. The process begins with quantifying the benefits of a proposed project in terms of the change in expected average crash frequency.

Section 7.4.1 provides guidance on how to use the *Part C* safety prediction methodology, the *Part D* AMFs, or locally developed AMFs, to estimate the change in expected average crash frequency for a proposed project. Section 7.4.2 provides guidance for how to estimate the change in expected average crash frequency when there is no applicable *Part C* methodology, no applicable SPF, and no applicable AMF.

Two types of methods are outlined in the chapter for estimating change in average crash frequency in terms of a monetary value. In benefit-cost analysis, the expected reduction in crash frequency by severity level is converted to monetary values, summed, and compared to the cost of implementing the countermeasure. In cost-effectiveness analysis, the expected change in average crash frequency is compared directly to the cost of implementing the countermeasure.

Depending on the objective of the evaluation, the economic appraisal methods described in this chapter can be used by highway agencies to:

1. Identify economically justifiable projects where the benefits are greater than the costs, and
2. Rank countermeasure alternatives for a given site.

Estimating the cost associated with implementing a countermeasure follows the same procedure as performing cost estimates for other construction or program implementation projects. *Chapter 6* of the *AASHTO Redbook* provides guidance regarding the categories of costs and their proper treatment in a benefit-cost or economic appraisal.(1)

The ultimate decision of which countermeasure implementation projects are constructed involves numerous considerations beyond those presented in *Chapter 7*. These considerations assess the overall influence of the projects, as well as the current political, social, and physical environment surrounding their implementation.

Chapter 8 presents methods that are intended to identify the most cost-efficient mix of improvement projects over multiple sites, but can also be applied to compare alternative improvements for an individual site.

7.9. SAMPLE PROBLEM

The sample problem presented here illustrates the process for calculating the benefits and costs of projects and subsequent ranking of project alternatives by three of the key ranking criteria illustrated in Section 7.6: cost-effectiveness analysis, benefit-cost analysis, and net present value analysis.

7.9.1. Economic Appraisal

Background/Information

The roadway agency has identified countermeasures for application at Intersection 2. Exhibit 7-8 provides a summary of the crash conditions, contributory factors, and selected countermeasures.

Exhibit 7-8: Summary of Crash Conditions, Contributory Factors, and Selected Countermeasures

Data	Intersection 2
Major/Minor AADT	22,100 / 1,650
Predominate Collision Types	Angle Head-On
Crashes by Severity	
Fatal	6%
Injury	65%
PDO	29%
Contributory Factors	Increase in traffic volumes
	Inadequate capacity during peak hour
	High travel speeds during off-peak
Selected Countermeasure	Install a Roundabout

The Question

What are the benefits and costs associated with the countermeasures selected for Intersection 2?

The Facts

Intersections:

- AMFs for installing a single-lane roundabout in place of a two-way stop controlled intersection (see *Chapter 14*);

- Total crashes = 0.56; and,
- Fatal and injury crashes = 0.18.

Assumptions

The roadway agency has the following information:

- Calibrated SPF and dispersion parameters for the intersection being evaluated;
- Societal crash costs associated with crash severities;
- Cost estimates for implementing the countermeasure;
- Discount rate (minimum rate of return);
- Estimate of the service life of the countermeasure; and,
- The roadway agency has calculated the EB-adjusted expected average crash frequency for each year of historical crash data.

The sample problems provided in this section are intended to demonstrate application of the economic appraisal process, not predictive methods. Therefore, simplified crash estimates for the existing conditions at Intersection 2 were developed using predictive methods outlined in *Part C* and are provided in Exhibit 7-9.

The simplified estimates assume a calibration factor of 1.0, meaning that there are assumed to be no differences between the local conditions and the base conditions of the jurisdictions used to develop the base SPF model. AMFs that are associated with the countermeasures implemented are provided. All other AMFs are assumed to be 1.0, meaning there are no individual geometric design and traffic control features that vary from those conditions assumed in the base model. These assumptions are for theoretical application and are rarely valid for application of predictive methods to actual field conditions.

Exhibit 7-9: Expected Average Crash Frequency at Intersection 2 WITHOUT Installing the Roundabout

Year in service life (y)	Major AADT	Minor AADT	$N_{expected(TOT)}$	$N_{expected(FI)}$
1	23,553	1,758	10.4	5.2
2	23,906	1,785	10.5	5.3
3	24,265	1,812	10.5	5.3
4	24,629	1,839	10.6	5.4
5	24,998	1,866	10.7	5.4
6	25,373	1,894	10.7	5.4
7	25,754	1,923	10.8	5.5
8	26,140	1,952	10.9	5.5
9	26,532	1,981	11.0	5.5
10	26,930	2,011	11.0	5.6
Total			107.1	54.1

The roadway agency finds the societal crash costs shown in Exhibit 7-10 acceptable. The agency decided to conservatively estimate the economic benefits of the countermeasures. Therefore, they are using the average injury crash cost (i.e., the average value of a fatal (K), disabling (A), evident (B), and possible injury crash (C) as the crash cost value representative of the predicted fatal and injury crashes.

Exhibit 7-10: Societal Crash Costs by Severity

Injury Severity	Estimated Cost
Fatality (K)	$4,008,900
Cost for crashes with a fatal and/or injury (K/A/B/C)	$158,200
Disabling Injury (A)	$216,000
Evident Injury (B)	$79,000
Possible Injury (C)	$44,900
PDO (O)	$7,400

Source: Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries, FHWA - HRT - 05-051, October 2005.

Exhibit 7-11 summarizes the assumptions regarding the service life for the roundabout, the annual traffic growth at the site during the service life, the discount rate and the cost of implementing the roundabout.

Exhibit 7-11: Remaining Assumptions

	Intersection 2
Countermeasure	Roundabout
Service Life	10 years
Annual Traffic Growth	2%
Discount Rate (i)	4.0%
Cost Estimate	$695,000

Method

The following steps are required to solve the problem.

- STEP 1 - Calculate the expected average crash frequency at Intersection 2 *without* the roundabout.
- STEP 2 - Calculate the expected average crash frequency at Intersection 2 *with* the roundabout.
- STEP 3 - Calculate the change in expected average crash frequency for total, fatal and injury, and PDO crashes.
- STEP 4 - Convert the change in crashes to a monetary value for each year of the service life.
- STEP 5 - Convert the annual monetary values to a single present value representative of the total monetary benefits expected from installing the countermeasure at Intersection 2.

A summary of inputs, equations, and results of economic appraisal conducted for Intersection 2 is shown in Exhibit 7-12. The methods for conducting the appraisal are outlined in detail in the following sections.

Exhibit 7-12: Economic Appraisal for Intersection 2

ROADWAY SEGMENT ACCIDENT PREDICTION WORKSHEET	
General Information	**Site Information**
Analyst: Mary Smith	Highway: US71
Agency or Company: State DOT	Roadway Section: ______
Date Performed: 02/03/02	Jurisdiction: ______
Analysis Time Period: _____ ______	Analysis Year: 2002
Input Data	
Major/Minor AADT (veh/day)	12,000 / 1,200
Countermeasure	Roundabout
Service Life ($Years_{SL}$)	10 years
Annual Traffic Volume Growth Rate	1.5%
Discount Rate (i)	4.0%
Cost Estimate	$2,000,000
Societal Crash Costs by Severity	
Fatal and Injury	$158,200
Property Damage Only	$7,400
Base Model	
Four-Legged Two-Way Stop Controlled Intersection Multiple Vehicle Collisions (See Chapter 12)	$N_{br} = N_{spf\ rs} \times (AMF_{1r} \times AMF_{2r} \times \ldots \times AMF_{nr})$
EB-Adjusted Expected Average Crash Frequency	
Expected Crashes without Roundabout	See Exhibit 7-9
Expected Crashes with Roundabout Equations 7-6, 7-7	See Exhibit 7-13 and Exhibit 7-14
Expected Change in Crashes Equations 7-8, 7-9, 7-10	See Exhibit 7-15
Yearly Monetary Value of Change in Crashes Equations 7-11, 7-12, 7-13	See Exhibit 7-16
Present Value of Change in Crashes Equations 7-14, 7-15	See Exhibit 7-17
Benefit of installing a roundabout at Intersection 2	$36,860,430

STEP 1 - Calculate the expected average crash frequency at Intersection 2 WITHOUT the roundabout.

The *Part C* prediction method can be used to develop the estimates. Exhibit 7-9 summarizes the EB-adjusted expected crash frequency by severity for each year of the expected service life of the project.

STEP 2 - Calculate the expected average crash frequency at Intersection 2 WITH the roundabout.

Calculate EB-adjusted total (TOT) and fatal and injury (FI) crashes for each year of the service life (y) assuming the roundabout is installed.

Multiply the AMF for converting a stop-controlled intersection to a roundabout found in *Chapter 14* (restated below in Exhibit 7-13) by the expected average crash frequency calculated above in *Exhibit 7-6* using Equations 7-6 and 7-7.

$$N_{expected\ \ roundabout\ (TOTAL)} = N_{expected(TOTAL)} \times AMF_{(TOTAL)} \quad (7\text{-}6)$$

$$N_{expected\ roundabout\ (FI)} = N_{expected(FI)} \times AMF_{(FI)} \quad (7\text{-}7)$$

Where,

$N_{expected\ \ roundabout\ \ (TOTAL)}$ = EB-adjusted expected average crash frequency in year *y* WITH the roundabout installed;

$N_{expected\ roundabout\ i(FI)}$ = EB-adjusted expected average fatal and injury crash frequency in year *y* WITH the roundabout installed;

$N_{expected\ (TOTAL)}$ = EB-adjusted expected average total crash frequency in year *y* WITHOUT the roundabout installed;

$N_{expected\ (FI)}$ = EB-adjusted expected average fatal and injury crash frequency in year *y* WITHOUT the roundabout installed;

$AMF_{(TOTAL)}$ = Accident Modification Factor for total crashes; and,

$AMF_{(FI)}$ = Accident Modification Factor for fatal and injury crashes.

Exhibit 7-13 summarizes the EB-adjusted average fatal and injury crash frequency for each year of the service life assuming the roundabout is installed.

Exhibit 7-13: Expected Average FI Crash Frequency at Intersection 2 WITH the Roundabout

Year in Service Life (y)	$N_{expected(FI)}$	$AMF_{(FI)}$	$N_{expected\ roundabout(FI)}$
1	5.2	0.18	0.9
2	5.3	0.18	1.0
3	5.3	0.18	1.0
4	5.4	0.18	1.0
5	5.4	0.18	1.0
6	5.4	0.18	1.0
7	5.5	0.18	1.0
8	5.5	0.18	1.0
9	5.5	0.18	1.0
10	5.6	0.18	1.0
Total			9.9

Exhibit 7-14 summarizes the EB-adjusted average total crash frequency for each year of the service life assuming the roundabout is installed.

Exhibit 7-14: Expected Average Total Crash Frequency at Intersection 2 WITH the Roundabout

Year in service life (y)	$N_{expected(TOTAL)}$	$AMF_{(TOTAL)}$	$N_{expected\ roundabout(TOTAL)}$
1	10.4	0.56	5.8
2	10.5	0.56	5.9
3	10.5	0.56	5.9
4	10.6	0.56	5.9
5	10.7	0.56	6.0
6	10.8	0.56	6.0
7	10.8	0.56	6.0
8	10.9	0.56	6.1
9	11.0	0.56	6.2
10	11.0	0.56	6.2
Total			60.0

STEP 3 - Calculate the expected change in crash frequency for total, fatal and injury, and PDO crashes.

The difference between the expected average crash frequency with and without the countermeasure is the expected change in average crash frequency. Equations 7-8, 7-9, and 7-10 are used to estimate this change for total, fatal and injury, and PDO crashes.

$$\Delta N_{expected\ (FI)} = N_{expected(FI)} - N_{expected\ roundabout(FI)} \quad (7\text{-}8)$$

$$\Delta N_{expected(TOTAL)} = N_{expected(TOTAL)} - N_{expected\ roundabout(TOTAL)} \quad (7\text{-}9)$$

$$\Delta N_{expected(PDO)} = N_{expected(TOTAL)} - N_{expected(FI)} \quad (7\text{-}10)$$

Where,

$\Delta N_{expected(TOTAL)}$ = Expected change in average crash frequency due to implementing countermeasure;

$\Delta N_{expected(FI)}$ = Expected change in average fatal and injury crash frequency due to implementing countermeasure; and,

$\Delta N_{expected(PDO)}$ = Expected change in average PDO crash frequency due to implementing countermeasure.

Exhibit 7-15 summarizes the expected change in average crash frequency due to installing the roundabout.

Exhibit 7-15: Change in Expected Average in Crash Frequency at Intersection 2 WITH the Roundabout

Year in service life, *y*	$\Delta N_{expected(TOTAL)}$	$\Delta N_{expected(FI)}$	$\Delta N_{expected(PDO)}$
1	4.6	4.3	0.3
2	4.6	4.3	0.3
3	4.6	4.3	0.3
4	4.7	4.4	0.3
5	4.7	4.4	0.3
6	4.7	4.4	0.3
7	4.8	4.5	0.3
8	4.8	4.5	0.3
9	4.8	4.5	0.3
10	4.8	4.6	0.2
Total	47.1	44.2	2.9

STEP 4 - Convert Change in Crashes to a Monetary Value

The estimated reduction in average crash frequency can be converted to a monetary value for each year of the service life using Equations 7-11 through 7-13.

$$AM_{(PDO)} = \Delta N_{expected(PDO)} \times CC_{(FI)} \qquad (7\text{-}11)$$

$$AM_{(FI)} = \Delta N_{expected(FI)} \times CC_{(FI)} \qquad (7\text{-}12)$$

$$AM_{(TOTAL)} = AM_{(PDO)} \times AM_{(FI)} \qquad (7\text{-}13)$$

Where,

$AM_{(PDO)}$ = Monetary value of the estimated change in average PDO crash frequency for year, *y*;

$CC_{(PDO)}$ = Crash cost for PDO crash severity;

$CC_{(FI)}$ = Crash cost for FI crash severity;

$AM_{(FI)}$ = Monetary value of the estimated change in fatal and injury average crash frequency for year y; and,

$AM_{(TOTAL)}$ = Monetary value of the total estimated change in average crash frequency for year y.

Exhibit 7-16 summarizes the monetary value calculations for each year of the service life.

Exhibit 7-16: Annual Monetary Value of Change in Crashes

Year in service life (y)	ΔN (FI)	FI Crash Cost	AM(FI)	ΔN(PDO)	PDO Crash Cost	AM(PDO)	AM(TOTAL)
1	4.3	$158,200	$680,260	0.3	$7,400	$2,220	$682,480
2	4.3	$158,200	$680,260	0.3	$7,400	$2,220	$682,480
3	4.3	$158,200	$680,260	0.3	$7,400	$2,220	$682,480
4	4.4	$158,200	$696,080	0.3	$7,400	$2,220	$698,300
5	4.4	$158,200	$696,080	0.3	$7,400	$2,220	$698,300
6	4.4	$158,200	$696,080	0.3	$7,400	$2,220	$698,300
7	4.5	$158,200	$711,900	0.3	$7,400	$2,220	$714,120
8	4.5	$158,200	$711,900	0.3	$7,400	$2,220	$714,120
9	4.5	$158,200	$711,900	0.3	$7,400	$2,220	$714,120
10	4.6	$158,200	$727,720	0.2	$7,400	$1,480	$729,200

STEP 5 – Convert Annual Monetary Values to a Present Value

The total monetary benefits expected from installing a roundabout at Intersection 2 are calculated as a present value using Equations 7-14 and 7-15.

Note: A 4% discount rate is assumed for the conversion of the annual values to a present value.

Convert the annual monetary value to a present value for each year of the service life.

$$PV_{benefits} = TotalAnnualMonetaryBenefits \times (P/F, i, y) \quad (7\text{-}14)$$

Where,

$PV_{benefits}$ = Present value of the project benefits per site in year y;

(P/F, i, y) = Factor that converts a single future value to its present value, calculated as (1+i)-y;

i = Discount rate (i.e., the discount rate is 4%, i = 0.04); and,

y= Year in the service life of the countermeasure.

If the annual project benefits are uniform, then the following factor is used to convert a uniform series to a single present worth:

$$(P/A, i, y) = \frac{(1.0 + i)^{(y)} - 1.0}{i \times (1.0 + i)^{(y)}} \quad (7\text{-}15)$$

Where,

(P/A, i, y) = a factor that converts a series of uniform future values to a single present value.

Exhibit 7-17 summarizes the results of converting the annual values to present values.

Exhibit 7-17: Converting Annual Values to Present Values

Year in service life (y)	(P/A, i, y)	$AM_{(TOT)}$	Present Value
1	1.0	$682,480	$682,480
2	1.9	$682,480	$1,296,710
3	2.8	$682,480	$1,910,940
4	3.6	$698,300	$2,513,880
5	4.5	$698,300	$3,142,350
6	5.2	$698,300	$3,631,160
7	6.0	$714,120	$4,284,720
8	6.7	$714,120	$4,784,600
9	7.4	$714,120	$5,284,490
10	8.1	$729,200	$5,906,520
Total			$33,437,850

The total present value of the benefits of installing a roundabout at Intersection 2 is the sum of the present value for each year of the service life. The sum is shown above in Exhibit 7-17.

Results

The estimated present value monetary benefit of installing a roundabout at Intersection 2 is $33,437,850.

The roadway agency estimates the cost of installing the roundabout at Intersection 2 is $2,000,000.

If this analysis were intended to determine whether the project is cost effective, the magnitude of the monetary benefit provides support for the project. If the monetary benefit of change in crashes at this site were to be compared to other sites the BCR could be calculated and used to compare to other projects to identify the most economically-efficient project.

7.10. REFERENCES

1. AASHTO. *A Manual of User Benefit Analysis for Highways, 2nd Edition.* American Association of State Highway and Transportation Officials, Washington, DC, 2003.
2. Council, F.M., E. Zaloshnja, T. Miller, and B. Persaud. *Crash Cost Estimates by Maximum Police Reported Injury Severity within Selected Crash Geometries*. Publication No. FHWA-HRT-05-051, Federal Highway Administration, U.S. Department of Transportation, October 2005.
3. Harwood, D.W. et al. *Safety Analyst: Software Tools for Safety Management of Specific Highway Sites Task M Functional Specification for Module 3* – Economic Appraisal and Priority Ranking GSA Contract No. GS-23F-0379K Task No. DTFH61-01-F-00096. November 2003. More information available from http://www.safetyanalyst.org.

APPENDIX A – DATA NEEDS AND DEFINITIONS FOR CHAPTER 7

A.1 Data Needs to Calculate Change in Crashes

Calculating the benefits of a countermeasure or set of countermeasures is a two step process. The first step is to calculate the change in crash frequency and the second is to calculate the monetary value of the change in crashes. The data needed for both of these steps are described below.

1. Calculate Change in Crashes

   The data needed to estimate change in crashes by severity are defined below.

- **Crash history** at the site by severity;
- **Current Average Annual Daily Traffic** (AADT) volumes for the site;
- **Expected implementation year** for the countermeasure(s); and,
- **Future AADT** for the site that correspond with the year in which the countermeasure is implemented.
- **Safety Performance Function (SPF)** for current site conditions (e.g., urban, four-legged, signalized intersection) and for total crashes (TOT) and for fatal and injury crashes (FI). SPFs may be locally developed or calibrated to local conditions.
- If necessary, an **SPF** for site conditions with the countermeasure implemented (e.g. urban, four-legged, roundabout controlled intersection) and for total crashes (TOT) and for fatal and injury crashes (FI). SPFs may be locally developed or calibrated to local conditions.
- **Accident Modification Factors (AMFs)** for the countermeasures under consideration. AMFs are a decimal that when multiplied by the expected average crash frequency without the countermeasure produces the expected average crash frequency with the countermeasure.

2. Convert Change in Crashes to a Monetary Value

The data needed to convert the change in crashes to a monetary value are described below.

- Accepted **monetary value of crashes** by collision type and/or crash severity

State and local jurisdictions often have accepted dollar value of crashes by collision type and/or crash severity that are used to convert the estimated change in crash reduction to a monetary value. The most recent societal costs by severity documented in the October 2005 Federal Highway Administration (FHWA) report "Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries" are listed below (values shown below are rounded to the nearest hundred dollars).[2]

- Fatality (K) = $4,008,900/fatal crash;

- Crashes that include a fatal and/or injury (K/A/B/C) = $158,200/ fatal and/or injury crash;
- Injury (A/B/C) = $82, 600/ injury crash;
- Disabling Injury (A) = $216,000/disabling injury crash;
- Evident Injury (B) = $79,000/evident injury crash;
- Possible Injury (C) = $44,900/possible injury crash; and,
- PDO (O) = $7,400/PDO crash.

The most recent mean comprehensive crash costs by type (i.e., single-vehicle rollover crash, multiple vehicle rear-end crash, and others) are also documented in the October 2005 FHWA report.

The monetary values used to represent the change in crashes are those accepted and endorsed by the jurisdiction in which the safety improvement project will be implemented.

A.2 Service Life of the Improvement Specific to the Countermeasure

All improvement projects have a service life. In terms of a countermeasure, the service life corresponds to the number of years in which the countermeasure is expected to have a noticeable and quantifiable effect on the crash occurrence at the site. Some countermeasures, such as pavement markings, deteriorate as time passes, and need to be renewed. For other countermeasures, other roadway design modifications and changes in the surrounding land uses that occur as time passes may influence the crash occurrence at the site, reducing the effectiveness of the countermeasure. The service life of a countermeasure reflects a reasonable time period in which roadway characteristics and traffic patterns are expected to remain relatively stable.

A.3 Discount Rate

The discount rate is an interest rate that is chosen to reflect the time value of money. The discount rate represents the minimum rate of return that would be considered by an agency to provide an attractive investment. Thus, the minimum attractive rate of return is judged in comparison with other opportunities to invest public funds wisely to obtain improvements that benefit the public. Two basic factors to consider when selecting a discount rate:

1. The discount rate corresponds to the treatment of inflation (i.e., real dollars versus nominal dollars) in the analysis being conducted. If benefits and costs are estimated in real (uninflated) dollars, then a real discount rate is used. If benefits and costs are estimated in nominal (inflated) dollars, then a nominal discount rate is used.
2. The discount rate reflects the private cost of capital instead of the public-sector borrowing rate. Reflecting the private cost of capital implicitly accounts for the element of risk in the investment. Risk in the investment corresponds to the potential that the benefits and costs associated with the project are not realized within the given service life of the project.

Discount rates are used for the calculation of benefits and costs for all improvement projects. Therefore, it is reasonable that jurisdictions are familiar with the discount rates commonly used and accepted for roadway improvements. Further guidance is found in the American Associate of State Highway and Transportation Officials (AASHTO) publication entitled *A Manual of User Benefit Analysis for Highways* (also known as the AASHTO Redbook).[(1)]

A.4 Data Needs to Calculate Project Costs

Highway agencies and local jurisdictions have sufficient experience with and established procedures for estimating the costs of roadway improvements. Locally derived costs based on specific site and countermeasure characteristics are the most statistically reliable costs to use in the economic appraisal of a project. It is anticipated that costs of implementing the countermeasures will include considerations such as right-of-way acquisition, environmental impacts, and operational costs.

A.5 Appendix References

1. AASHTO. *A Manual of User Benefit Analysis for Highways, 2nd Edition.* American Association of State Highway and Transportation Officials, Washington, DC, 2003.

2. Council, F.M., E. Zaloshnja, T. Miller, and B. Persaud. *Crash Cost Estimates by Maximum Police Reported Injury Severity within Selected Crash Geometries*. Publication No. FHWA-HRT-05-051, Federal Highway Administration, Washington, DC, October 2005.

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