Highway Safety Benefit–Cost Analysis Guide

FHWA Safety Program

U.S. Department of Transportation
Federal Highway Administration

Safe Roads for a Safer Future
Investment in roadway safety saves lives

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FOREWORD

The purpose of the Highway Safety Benefit-Cost Analysis Guide (this Guide) is to assist transportation agencies in making consistent and theoretically sound decisions for economically evaluating and ranking safety countermeasures. Transportation professionals can use the methods described to analyze both site-specific and systemic safety approaches with single or multiple countermeasures. This Guide is intended as a user-friendly technical reference which transportation professionals can use with no prior experience with economic evaluation techniques. This Guide provides example calculations throughout the document to assist transportation professionals in understanding benefit-cost analysis (BCA) concepts and applying them for safety applications.

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The purpose of the Highway Safety Benefit-Cost Analysis (BCA) Guide is to assist transportation agencies in making consistent and sound investment decisions. The target audience includes transportation professionals such as traffic engineers, highway safety engineers, and planners conducting highway safety BCA for projects and programs. This Guide will help these users to quantify the costs, and direct and indirect safety-related benefits of project alternatives. Direct safety benefits include the expected change in crash frequency and severity. Indirect benefits include the operational and environmental benefits that result from a reduction in crashes (e.g., reduced delay, fuel use, and emissions). Readers will understand the methods, data requirements, and considerations associated with BCA. Examples demonstrate the application of the methods in various scenarios, including both site-specific and systemic projects with single or multiple countermeasures. Conducting consistent and reliable BCA will support decision making, optimize the return on investments, and increase the effectiveness of projects and programs.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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ACRONYMS

AADT	Annual Average Daily Traffic
AIS	Abbreviated Injury Scale
BCA	Benefit-Cost Analysis
BCR	Benefit-Cost Ratio
CFR	Code of Federal Regulations
CMAQ	Congestion Mitigation and Air Quality
CMF	Crash Modification Factor
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
HSIP	Highway Safety Improvement Program
KABCO	National Safety Council Injury Scale
LCCA	Life-Cycle Cost Analysis
MMUCC	Model Minimum Uniform Crash Criteria
MPO	Metropolitan Planning Organization
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
NHTSA	National Highway Traffic Safety Administration
NPV	Net Present Value
OMB	Office of Management and Budget
PDO	Property Damage Only
PHT	Person Hours of Travel
SHRP2	Second Strategic Highway Research Program
SPF	Safety Performance Function
TAC	Technical Advisory Committee
TRB	Transportation Research Board
USDOT	United States Department of Transportation
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
VSL	Value of a Statistical Life

EXECUTIVE SUMMARY

Transportation agencies must continuously justify the economic effectiveness of their programs and expenditures. Economically effective and efficient projects are particularly important for safety programs that establish aggressive targets and require greater fiscal responsibility and stewardship to achieve these goals. Further, transportation professionals routinely assess and prioritize projects based on costs and benefits related to pavement preservation, operational performance, and environmental impacts. While guidance and tools are available to analyze the direct safety-related benefits and costs of projects, there is a need to consider the complete lifecycle cost and benefits of all projects, including the indirect safety-related benefits.

There are many reasons to perform a benefit-cost analysis (BCA) for transportation projects. Some funding programs require BCA (e.g., TIGER and INFRA grants), while other agencies establish a policy or procedure to perform BCA. In either case, the following are specific benefits to employing BCA in the roadway safety management and project development processes:

- **Best Return on Investment:** Economic analysis can help in planning, programming, and implementing transportation programs with the best rate of return for any given budget. It can also help to determine an optimal program budget.
- **Cost-Effective Design and Construction:** Economic analysis can inform agencies as to which of several project designs to implement at the lowest lifecycle cost to the agency, lowest delay cost to the traveler, highest safety benefit to users, and the best affordable balance between these costs.
- **Understanding Complex Projects:** In a time of growing public scrutiny of new and costly road projects, transportation agencies and other decision makers need to understand the comprehensive costs and benefits of these projects. A rigorous BCA can help to quantify and compare the impacts of project alternatives on safety, mobility, the environment, and regional economies.
- **Documentation of Decision Process:** The discipline of quantifying and valuing the benefits and costs of highway projects also provides documentation to justify and explain the decision process to legislatures and the public.

The Highway Safety Benefit-Cost Analysis Guide provides agencies with the knowledge, tools, and insights to perform reliable highway safety BCA and communicate the results. For those new to BCA, this Guide introduces the BCA process and describes fundamental concepts and factors to consider when preparing for BCA. For those familiar with BCA, this Guide can help to enhance current practices through a discussion of common challenges and opportunities to overcome those challenges. This Guide also defines typical project costs and benefits included in BCA and provides default values to monetize these benefits. This Guide provides instruction and examples of how to estimate and monetize safety-related project benefits, including the expected change in crashes and the resulting operational and environmental benefits. Finally, this Guide provides considerations and examples related to the communication of BCA results.

In summary, BCA is critical to understanding the potential return on investment from potential projects and programs. While BCA is a policy or procedural decision, this Guide can help agencies to understand the value of performing BCA, consider the data requirements and resources to perform BCA, and determine the specific format and parameters of the analysis. This Guide can also help transportation professionals perform reliable BCA and use the results to inform decisions and improve investments.

1. OVERVIEW OF GUIDE

1.1 INTRODUCTION AND PURPOSE

This Guide focuses on the safety benefits of competing engineering projects (i.e., expected difference in crash frequency and severity) and the benefits derived from differences in safety performance (e.g., reduced delay, travel time, and emissions because of fewer crashes). While safety is a key factor in transportation decision-making, agencies may consider many factors in project selection and programming. The following is a list of other potential factors an agency may consider during project selection and programming:

- Other planned projects at the location (for safety improvement or otherwise).
- Right-of-way needs and acquisition.
- Operational efficiency.
- Environmental impacts and mitigation.
- Economic impacts.
- Social equity (distribution of investments across select population groups).
- Project readiness.
- Familiarity with the treatment's design, construction, and potential impacts.
- Public requests for improvement projects.
- Public acceptance and perception.

This Guide explains how to quantify the monetary benefits associated with expected differences in safety among project alternatives, and the indirect operational and environmental benefits (i.e., operational and environmental impacts that result from a change in safety performance). It focuses on project-level analysis of single or multiple improvements at a given location. It also covers network-level analysis for projects that include multiple locations (e.g., systemic improvements). This Guide focuses on economic analysis and only briefly discusses project prioritization within a program. It does not address behavioral measures or the direct benefits related to operations and the environment (i.e., those benefits not derived from a change in safety performance). Agencies may use other methods and tools to quantify the benefits of behavioral measures and non-safety factors (e.g., microsimulation to estimate operational impacts; noise and emissions models to estimate environmental impacts). Some of these non-safety factors (e.g., public acceptance) may be difficult to quantify and will require subjective weights to prioritize projects.

While this Guide provides methods and default values to monetize the direct and indirect safety benefits of alternatives, a benefit-cost analysis (BCA) is a policy or procedural decision where an agency defines the parameters. Agencies should develop a prioritization process that meets their specific needs, integrating quantitative safety and non-safety factors as needed.

A BCA is a policy or procedural decision where an agency defines the parameters.

1.2 TARGET AUDIENCE

This Guide is intended to meet the needs of transportation professionals conducting highway safety BCA for projects and programs. Transportation professionals, such as traffic and safety engineers or planners, are the target audience for this Guide. This Guide assumes these professionals are not economists and may not have formal training in economic evaluation techniques. Thus, this Guide describes basic concepts and terminology relating to BCA to support the needs of transportation professionals who may be new to BCA.

1.3 STRUCTURE OF THE GUIDE

This Guide is organized into nine chapters and an appendix. Chapter 2 introduces fundamental concepts of BCA and safety management, defines economic measures for BCA, provides an overview of BCA in the safety management and project development process, and identifies several related resources. Chapter 3 introduces project costs, including the costs to design, construct, operate, maintain, and rehabilitate the project. Chapter 4 introduces project benefits, identifying types of benefits included in highway safety BCA and default values to monetize benefits. Chapter 5 identifies factors to consider when preparing for BCA such as the base condition, analysis period, potential for uncertainty in the underlying data and analysis results, and discount rate. Chapter 6 describes how to estimate and monetize safety-related project benefits, including the expected change in crashes and the resulting change in operational and environmental measures. Chapter 7 presents hypothetical examples of BCA for projects with single countermeasures, multiple countermeasures, and multiple locations. Chapter 8 presents considerations and options for communicating BCA results to decision-makers. Chapter 9 presents a summary of this Guide with key takeaways. Appendix A provides a glossary of terms.

Complementary to this Guide, a spreadsheet-based BCA tool was developed to complete a BCA in accordance with the methods, assumptions, and data sources described in this Guide. The purpose of the Tool is to assist transportation professionals in generating results for presentation to colleagues, management, and the public. The Tool provides the framework for an efficient and repeatable process that facilitates communication of the results to diverse audiences.

2. OVERVIEW OF BCA FOR SAFETY

A BCA is a key component of a comprehensive project or program development process that considers quantitative and qualitative impacts of highway investments. Transportation agencies use these economic evaluation techniques to identify, quantify, and assign value to the economic benefits and costs of highway projects and programs over multiyear timeframes. This chapter introduces fundamental concepts of BCA and the safety management process, defines economic measures for BCA, provides an overview of BCA in the safety management process and project development process, and identifies several related resources.

Chapter 2 At-A-Glance

Chapter 2 is divided into six sections:

- Section 2.1 defines BCA.
- Section 2.2 defines safety management, including the crash-based approach, the systemic approach, and how these two complementary approaches provide a comprehensive approach to safety management.
- Section 2.3 introduces economic measures used to compare and rank alternatives, including present value cost (PVC), present value benefit (PVB), benefit-cost ratio (BCR), net present value (NPV), cost-effectiveness index (CEI), and payback period.
- Section 2.4 describes the use of BCA in safety management, including the use of BCA to achieve the most efficient or effective project.
- Section 2.5 provides a brief description of several highway safety BCA resources.
- Section 2.6 provides a summary of the chapter.

2.1 WHAT IS BENEFIT-COST ANALYSIS?

A BCA is a systematic process for calculating and comparing the benefits and costs of project alternatives.[1] A BCA attempts to capture all benefits to society from a project or course of action, and the cost to achieve those benefits, regardless of which party realizes the benefits and costs, or the form of these benefits and costs. Using BCA, transportation professionals can compare present value costs and benefits among alternatives for a given analysis period. Used properly, BCA reveals the most economically-efficient investment alternative (i.e., the one that maximizes the net benefits to society relative to the allocation of resources).

A BCA is systematic process for calculating and comparing benefits and costs of a project.

A BCA differentiates costs and benefits by project costs (or agency costs), project benefits (or user benefits), and externalities (or non-user benefits). Project benefits and externalities include costs avoided, but also include negative benefits (disbenefits) such as increased crashes or air emissions. Analysts monetize project benefits by assigning dollar values to the different effects. For example, if there is an expected change in crash frequency associated with a project alternative, compared to the base condition (e.g., the do-nothing alternative), then the analyst multiplies the expected change in crashes by the average cost of a crash. If there are negative impacts, then these appear as negative benefits. Table 1 summarizes common project costs, project benefits, and externalities.

Table 1. Cost and benefit categories.

Project Costs (Agency Costs)	Project Benefits (User Benefits)	Externalities (Non-User Benefits)
• Design and engineering. • Land acquisition. • Construction. • Reconstruction/ Rehabilitation. • Preservation. • Routine maintenance. • Mitigation (e.g., noise barriers). • Utility relocation. • Energy.	• Reduced travel time and delay. • Improved travel time reliability. • Reduced crash frequency and/or severity. • Reduced vehicle operating cost.	• Reduced air emissions. • Reduced noise. • Reduced impacts to natural habitat and wetlands.

2.2 WHAT IS SAFETY MANAGEMENT?

Safety management typically comprises three components: planning, implementation, and evaluation. More specifically, this includes the identification of opportunities for safety improvement, the implementation of projects to target the identified safety opportunities, and the evaluation of implemented projects to understand the effectiveness of investments.

Safety management includes planning, implementation, and evaluation.

There are two general approaches to safety management: 1) selecting and treating sites based on site-specific crashes (also referred to as the crash-based approach in this Guide), and 2) selecting and treating sites based on site-specific geometric and operational attributes associated with increased crash potential (referred to as the systemic approach in this Guide).

The crash-based and systemic approaches are complementary and support a comprehensive approach to safety management. To be the most effective, both approaches should focus on sites with the greatest potential for safety improvement (i.e., preventing future crashes and reducing fatalities and injuries). For both approaches, it is important to use repeatable and reliable, data-driven methods such as BCA to inform decisions.

2.2.1 Crash-Based Approach

The crash-based approach involves the identification and evaluation of individual locations with high potential for safety performance improvement. Transportation agencies use data analysis techniques to identify locations where a safety improvement opportunity exists and to select appropriate countermeasures that target site-specific crash-contributing factors.

In the crash-based approach, analysts identify sites based on crash-based performance measures. The more rigorous crash-based measures use the empirical Bayes (EB) method to incorporate crash predictions from safety performance functions (SPFs) and site-specific crash history. Once an agency identifies a list of sites, a multidisciplinary analysis team performs a detailed review of site-specific crash history and characteristics (e.g., road users, adjacent land use, geometry, and traffic operations) to identify target crash types and crash-contributing factors. This provides the foundation for the identification and selection of appropriate countermeasures to mitigate the specific safety issues (e.g., crash patterns and contributing factors) at each site.[2,3,4]

2.2.2 Systemic Approach

The FHWA defines a systemic roadway safety improvement as a proven safety countermeasure that is widely implemented based on high-risk roadway features that are correlated with particular severe crash types (23 CFR 924.3).[5] FHWA describes systemic projects as having the following characteristics:[6]

- Safety opportunities identified through system-wide data, such as rural lane departure crashes, urban pedestrian crashes, or rural unsignalized intersection crashes. Often, these opportunities spread across a roadway network.
- Similar projects across a network to address high priority crash types and risk factors.
- Target specific roadway characteristics such as geometry, volume, or location frequently present in severe crashes.
- Improvements with proven countermeasures on sites identified by the presence of roadway factors correlated with specific crash types rather than site-specific crashes.
- Generally low-cost improvements (e.g., enhanced signing or striping, rumble strips, or signal heads upgrades). Higher-cost improvements are candidates for the systemic approach, but the improvement should be highly effective to justify the increased cost.

The following section describes the roadway safety management process that is generally applicable to both the crash-based and systemic approach.

2.2.3 Roadway Safety Management Process

The roadway safety management process is a six-step process as shown in Figure 1 and outlined in the Highway Safety Manual.[7]

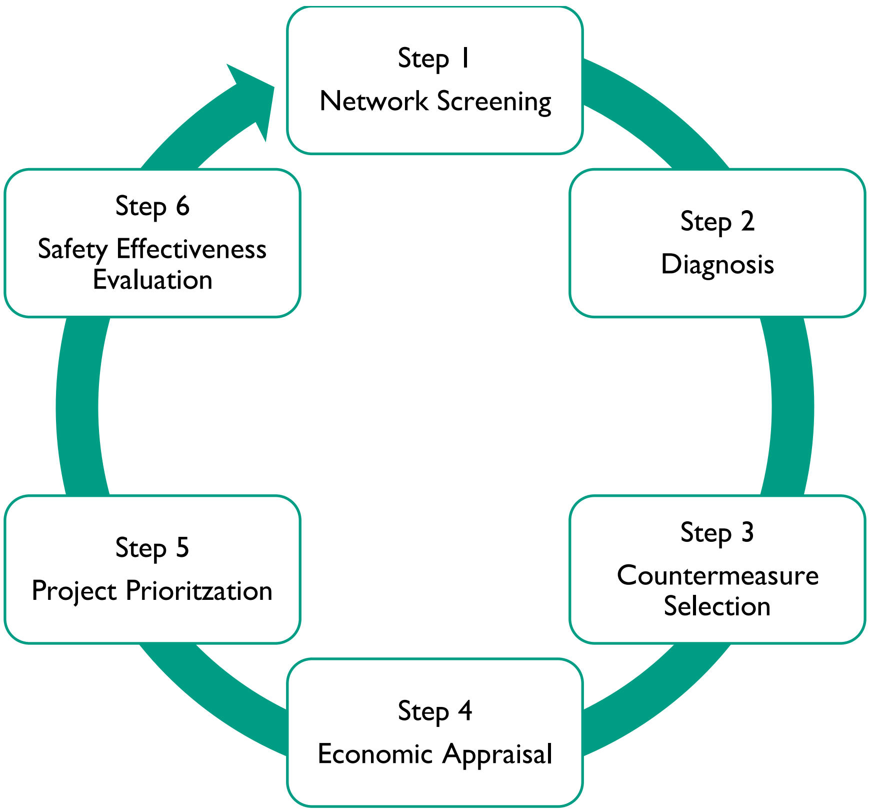

Figure 1. Chart. Roadway safety management process.

The objectives of this process are as follows.[4]

1. **Network Screening**: Identify locations that could benefit from treatments to improve safety performance (i.e., reduce crash frequency and severity).
2. **Diagnosis**: Understand collision patterns and crash contributing factors.
3. **Countermeasure Selection**: Identify, assess, and select appropriate countermeasures to target crash contributing factors and reduce crash frequency and severity at locations with potential for improvement.
4. **Economic Appraisal**: Estimate the economic cost and benefit associated with a particular countermeasure or set of countermeasures. This Guide focuses on the use of BCA in economic appraisal to consider the relative costs and benefits among alternatives.

5. **Project Prioritization**: Develop a prioritized list of projects to improve the safety performance (i.e., reduce crash frequency and severity) of the road network, considering available resources. Project prioritization involves policy-level decisions such as overall agency goals and may include multiple (and sometimes competing) factors such as safety, operational efficiency, environmental impacts, and equity. This Guide does not cover project prioritization.
6. **Safety Effectiveness Evaluation**: Evaluate how a project (or group of projects) has affected the safety performance of the treated location(s) and the system. The evidence-based safety effectiveness estimates developed in step 6 (safety effectiveness evaluation) support future decisions.

The roadway safety management process is an integral part of the project development process. While the roadway safety management process focuses on safety performance, the results of countermeasure selection, economic appraisal, and project prioritization feed into the project development process (i.e., system planning, project planning, project design and construction, and system operations and maintenance).

2.3 ECONOMIC MEASURES FOR BCA

Agencies can use various measures, indices, and factors to compare and select among project alternatives. Table 2 lists common economic measures for BCA. Three of these measures (indicated in bold) directly compare monetary benefits and costs, which is needed to accurately assess the cost-effectiveness of project alternatives. Following the table is a detailed description of each measure.

Table 2. Comparison of economic appraisal measures.

Economic Measure	Considers Costs	Considers Benefits	Considers Monetary Costs and Benefits
Present value cost (PVC)	Yes	No	No
Present value benefit (PVB)	No	Yes	No
Cost-effectiveness index (CEI)	Yes	Yes	No
Benefit-cost ratio (BCR)	**Yes**	**Yes**	**Yes**
Net present value (NPV)	**Yes**	**Yes**	**Yes**
Payback period	**Yes**	**Yes**	**Yes**

2.3.1 Present Value Costs (PVC)

The PVC is the present value of all costs incurred from implementing a project over the service life (e.g., engineering, right-of-way, construction, maintenance, change in road user costs). A positive value of PVC represents funds expended; a negative value represents a savings or influx of funds.

2.3.2 Present Value Benefits (PVB)

The PVB is the monetized present value of the expected change in crashes from implementing a project (i.e., expected change in crashes multiplied by average crash costs). Benefits may include all crashes, although some agencies only consider the changes to fatal and serious injury crashes (or other crash type and/or severity combinations). A positive PVB represents a crash reduction; a negative value represents an increase in crashes.

2.3.3 Cost-Effectiveness Index (CEI)

The CEI is the average cost of a project to reduce one crash. The CEI is calculated by dividing the PVC by the expected number of crashes reduced over the service life of the project as shown in Figure 2. In general, a low CEI is desirable. The CEI is typically based on total crashes, but can be expressed in terms of a specific crash type or severity level (e.g., cost to reduce one fatal and serious injury crash). The CEI does not account for the monetary benefits. As such, it is not an appropriate measure to justify projects economically. It can, however, serve as a measure when it is difficult to monetize benefits (e.g., when an agency has not adopted crash cost values).

$$CEI = \frac{PVC}{crashes\ reduced}$$

Figure 2. Equation. Cost-effectiveness index.

2.3.4 Benefit-Cost Ratio (BCR)

The BCR is the ratio of present value benefits (including negative benefits) to present value costs (initial and continuing costs over the project lifecycle), as shown in Figure 3. In this context, the BCR is the same as the rate of return and return on investment. A BCR greater than 1.0 indicates that benefits exceed costs, and the project is economically justified. In general, a higher BCR is desirable. The BCR is most appropriate for prioritizing alternatives when funding restrictions apply (e.g., prioritizing countermeasures or locations within a project with a fixed budget).

$$BCR = \frac{PVB}{PVC}$$

Figure 3. Equation. Benefit-cost ratio.

2.3.5 Net Present Value (NPV)

The NPV is the difference between present value benefits and present value costs, as shown in Figure 4. NPV is also sometimes called net benefits or net present worth. If the NPV is greater than 0.0, then the benefits exceed the costs, and the project is economically justified. In general, a higher NPV is desirable. An agency can use NPV to determine the alternative with the highest benefits for a given project.

$$NPV = PVB - PVC$$

Figure 4. Equation. Net present value.

2.3.6 Payback Period

The payback period is the length of time, in years, to reach the breakeven point on the investment, measured from the end of construction to when the PVB equals the PVC.

2.3.7 Summary of Economic Measures

The BCR and NPV are generally the most appropriate measures to assess and prioritize project alternatives in highway safety BCA. The BCR is insensitive to the magnitude of net benefits; therefore, it may prioritize projects with relatively lower costs and benefits over those with higher net benefits. The use of NPV can help to identify projects with the higher net benefits. The payback period does not consider the full extent of benefits (i.e., only up to the value of costs).

The United States Department of Transportation (USDOT) recommends the use of BCR or NPV for most economic evaluations.(8) Analysts may consider a combination of measures (e.g., BCR and NPV) or other available BCA measures (e.g., equivalent uniform annual value approach or internal rate of return) depending on the policy or preference of the agency. Refer to resources such as the Transportation Systems Management and Operations Benefit-Cost Analysis Compendium for definitions of the equivalent uniform annual value approach and internal rate of return.(9) Chapter 7 illustrates the use of the BCR and NPV to assess alternatives through practical applications of BCA in various scenarios.

The BCR and NPV are often the most appropriate economic measures to assess alternatives.

2.4 USE OF HIGHWAY SAFETY BCA IN SAFETY MANAGEMENT AND PROJECT DEVELOPMENT

The safety management process and project development process often include the comparison of multiple project alternatives. This may include alternative designs for a specific location or alternative locations as part of a systemic improvement project. Highway safety BCA helps to compare the cost-effectiveness of alternative designs, and enables decision-makers, planners, highway designers, and traffic engineers to consider safety-motivated projects in conjunction with resurfacing, rehabilitation, reconstruction, and expansion projects.

Decision-makers use BCA to compare the cost-effectiveness of alternatives or projects.

Highway safety BCA can indicate which alternative provides the most efficient or effective safety benefit to highway users. The **most efficient** (i.e., most cost-effective) alternative provides the largest benefit per dollar spent (i.e., highest BCR). The **most effective** alternative provides the largest net benefit to the public (i.e., highest NPV).

In general, this Guide focuses on the use of BCA in economic appraisal to quantify, assess, and compare the costs and benefits of alternatives for a specific location. Specifically, this Guide will help users to quantify project benefits and costs to determine the most efficient and effective alternative. While BCA is essential to conducting economic appraisal, the results are also useful in project prioritization (i.e., the comparison of alternative projects as part of a program). This Guide covers project prioritization in the context of prioritizing alternatives within a project. This includes projects with multiple alternatives where some of the alternatives are subsets of a more comprehensive alternative. Further, this applies to the selection of a subset of multiple potential locations in a systemic improvement project. The following sections compare the use of BCR and NPV measures in prioritizing alternatives within a project to achieve the most efficient or effective project.

2.4.1 Prioritizing Locations to Achieve the Most Efficient Project

The efficiency of a project is assessed by the return on investment (i.e., the value achieved per dollar spent), and the BCR is an appropriate measure to achieve the most efficient project. To illustrate the use of BCR for achieving the most efficient safety improvement project, consider a group of 10 potential project locations. Table 3 shows the monetary benefits, costs, NPV, and BCR for each potential project location. Improvements are economically-justified at all potential locations (i.e., BCR greater than 1.0 and a positive NPV). Suppose the budget for this hypothetical systemic safety project is $80,000. Ranking the locations by BCR and NPV will illustrate the effectiveness of each measure in developing Alternative 1 and Alternative 2, respectively.

Table 3. Economic information for example project locations.

Location #	Benefits	Costs	NPV	BCR
1	$90,000	$30,000	$60,000	3.00
2	$50,000	$25,000	$25,000	2.00
3	$67,500	$20,000	$47,500	3.38
4	$100,000	$40,000	$60,000	2.50
5	$15,000	$7,500	$7,500	2.00
6	$60,000	$10,000	$50,000	6.00
7	$40,000	$10,000	$30,000	4.00
8	$25,000	$10,000	$15,000	2.50
9	$25,000	$5,000	$20,000	5.00
10	$15,000	$5,000	$10,000	3.00

Table 4 lists the priority ranking of locations by BCR. Locations for Alternative 1 are selected from the top of the list until the budget is filled. Rows shaded gray indicate locations that do not fit within the budget.

Table 4. BCR ranking of example project locations for Alternative 1.

Location #	Benefits	Costs	NPV	BCR
6	$60,000	$10,000	$50,000	6.00
9	$25,000	$5,000	$20,000	5.00
7	$40,000	$10,000	$30,000	4.00
3	$67,500	$20,000	$47,500	3.38
1	$90,000	$30,000	$60,000	3.00
10	$15,000	$5,000	$10,000	3.00
4	*$100,000*	*$40,000*	*$60,000*	*2.50*
8	*$25,000*	*$10,000*	*$15,000*	*2.50*
2	*$50,000*	*$25,000*	*$25,000*	*2.00*
5	*$15,000*	*$7,500*	*$7,500*	*2.00*

Table 5 lists the priority ranking of locations by NPV. Locations for Alternative 2 are selected from the top of the list until the budget is filled. Rows shaded gray indicate projects that do not fit within the budget.

Table 5. NPV ranking of example project locations for Alternative 2.

Location #	Benefits	Costs	NPV	BCR
1	$90,000	$30,000	$60,000	3
4	$100,000	$40,000	$60,000	2.5
6	$60,000	$10,000	$50,000	6
3	*$67,500*	*$20,000*	*$47,500*	*3.375*
7	*$40,000*	*$10,000*	*$30,000*	*4*
2	*$50,000*	*$25,000*	*$25,000*	*2*
9	*$25,000*	*$5,000*	*$20,000*	*5*
8	*$25,000*	*$10,000*	*$15,000*	*2.5*
10	*$15,000*	*$5,000*	*$10,000*	*3*
5	*$15,000*	*$7,500*	*$7,500*	*2*

Table 6 provides a comparison of the economic measures for selected locations in Table 4 and Table 5, representing Alternative 1 and Alternative 2, respectively. Bold numbers indicate the preferred alternative. Alternative 1, developed using the BCR, is clearly the preferred set of locations as it provides the highest benefits, NPV, and BCR. Alternative 1 provides the most efficient project because it results in the greatest benefits within a fixed cost.

Table 6. Alternative 1 and Alternative 2 economic comparison.

Economic Measure	Alternative 1	Alternative 2
Total Benefits	**$297,500**	$250,000
Total Costs	$80,000	$80,000
NPV	**$217,500**	$170,000
BCR	**3.72**	3.13

2.4.2 Prioritizing Locations to Determine the Most Effective Project

The effectiveness of a project is assessed by the overall benefits (i.e., the total value achieved), which is indicated by the highest NPV. When the budget of a project is fixed, and assuming that funds are expended up to the budget limit, the most efficient project is also the most effective. Again, the BCR is an appropriate measure to achieve the most efficient and effective project given a fixed budget. This section describes how to achieve the most effective project without consideration of budget.

While prioritizing potential locations using BCR yields the most efficient (cost-effective) project, in some cases agencies and the public may desire an economically-justified project with the highest possible benefits, regardless of the cost-efficiency of the investment. For example, stakeholders may call for additional spending to provide the greatest possible crash reduction at a high-profile site with an extraordinary crash history. The most cost-effective alternative may provide only a marginal reduction in crashes. Additionally, given the BCR ranking can favor a larger number of smaller-scale improvements at multiple locations, some agencies may decide to pursue fewer, more effective improvements to reduce the burden of project management.

Prioritization by NPV yields a ranking of maximum benefits in each alternative. However, as illustrated in the previous section, ranking by NPV can reduce the cost-effectiveness of the overall project and can guide funds towards less efficient investments. When selecting the most effective alternative with NPV, agencies may be ignoring the most cost-effective alternatives (i.e., the funds could have been spent on more efficient projects). If there were no budgetary limitations, NPV is the preferred prioritization measure.

2.4.3 Prioritizing Project Locations Without Monetized Benefits

In some scenarios, the monetary value of benefits cannot be determined or is not used in analysis. For example, if the severity distribution of the expected crash reduction is not well known, an agency may not be comfortable applying average crash costs to estimate the monetary benefits. In this case, the CEI is a suitable measure for prioritizing project locations. This measure incorporates the monetary costs with non-monetary benefits (i.e., change in the number of crashes). The CEI does not allow for direct consideration of non-safety benefits.

2.4.4 Optimizing Project Locations within a Program

Optimization is the process of organizing prioritized projects within program budget limitations and other constraints to maximize program effectiveness over time. Optimization methods use mathematical models to maximize the benefits of projects, both monetary and non-monetary, without exceeding the available budget. Optimization occurs after the initial economic analysis and includes only those projects that are economically-justified. As such, it does not affect the procedures described in the previous sections.

There are several optimization methods with various capabilities and constraints, including linear programming, integer programming, and dynamic programming. These methods are consistent with maximizing the BCR of a safety program. Integer programming is the most applicable to project optimization, where each project is either implemented or not. Refer to the Highway Safety Manual for further discussion of optimization methods.[7]

2.5 HIGHWAY SAFETY BCA RESOURCES

In addition to this Guide, the FHWA and State transportation agencies have produced numerous technical references relating to BCA. This section provides an overview of selected resources.

2.5.1 Highway Safety Manual

The Highway Safety Manual presents a science-based technical approach to conduct safety analysis for transportation facilities, including methods to predict the change in crashes resulting from the implementation of safety countermeasures.(7) The Highway Safety Manual provides methods for developing an effective roadway safety management program and evaluating its effects. The Highway Safety Manual provides tools to conduct quantitative safety analyses, allowing quantitative evaluation of safety alongside other transportation performance measures such as traffic operations, environmental impacts, and construction costs. The target audience of the Highway Safety Manual is a wide audience of transportation professionals at the State, county, metropolitan planning organization (MPO), or local level.

The Highway Safety Manual includes an overview of BCA in Chapter 7, *Economic Appraisal*. In addition, the Highway Safety Manual provides predictive methods to estimate crash frequency and severity. The user can employ these methods to estimate predicted or expected crashes for use in BCA.

2.5.2 Crash Costs for Highway Safety Analysis

The Crash Costs for Highway Safety Analysis guide describes the various sources of crash costs, current practices and crash costs used by States, critical considerations when modifying and applying crash unit costs, and an exploration of the feasibility of establishing national crash unit cost values.(10) The guide proposes a new set of national crash unit costs and procedures to 1) update the crash unit costs over time, and 2) adjust the crash unit costs to States based on State-specific cost of living, injury-to-crash ratios, and vehicle-to-crash ratio. This BCA guide and the related tool incorporate the suggested national crash unit costs as default values.

2.5.3 The Economic and Societal Impact of Motor Vehicle Crashes

The National Highway Traffic Safety Administration (NHTSA) published this study in 2014, later revised in 2015, representing the most recent research on the fiscal impact of motor vehicle crashes. The Economic and Societal Impact of Motor Vehicle Crashes presents the results of this research, quantifying the economic and societal costs resulting from motor vehicle crashes recorded in 2010.(11) The costs include aggregate increases in air emissions, vehicle operating costs, and travel time that result from crashes. This report provides perspective on the economic losses and societal harm that result from crashes, and supports government and private sector officials in structuring programs to reduce or prevent these losses. This BCA Guide uses results from the NHTSA report to monetize project benefits and externalities.

2.5.4 Economic Analysis Primer

USDOT developed the Economic Analysis Primer to provide a foundation for understanding the role of economic analysis in highway decision-making.[8] The Primer is oriented toward State and local officials who have responsibility for assuring that limited resources get targeted to their best uses and who account publicly for their decisions. It presents economic analysis as an integral component of a comprehensive infrastructure management approach that takes a long-term view of infrastructure performance and cost. The primer is nontechnical in its descriptions of economic methods, but it encompasses a full range of economic issues that are of potential interest to transportation officials. This BCA Guide briefly describes the use of the discount rate and risk analysis in highway safety BCA. Refer to the Primer for further details on these and other fundamental economic analysis concepts.

2.5.5 Operations Benefit/Cost Analysis Desk Reference

The Operations Benefit/Cost Analysis Desk Reference provides background information on BCA, including basic terminology and concepts.[1] The reference supports the needs of practitioners, new to BCA, who may be unfamiliar with the general process. The reference describes some of the more complex analytical concepts and latest research to support transportation professionals in conducting more advanced analyses. This BCA Guide focuses on the safety impacts of projects. If a safety project is also likely to impact operations, refer to the Operations Benefit/Cost Analysis Desk Reference to consider additional benefits. Some of the more advanced topics include capturing the impacts of travel time reliability, assessing the synergistic effects of combining different strategies, and capturing the benefits and costs of operations-supporting infrastructure such as traffic surveillance and communications.

2.5.6 Life-Cycle Cost Analysis Primer

This BCA Guide focuses on the comparison of both project benefits and costs in selecting and prioritizing alternatives. Lifecycle cost analysis (LCCA) is an approach used to compare the costs of project alternatives, assuming the agency has decided to implement a project at a given location. Analysts should only use LCCA to compare project alternatives that would yield the same benefits. For example, LCCA would be an appropriate tool to compare two alternative bridge replacement designs that would result in the same level of service. Refer to the Life-Cycle Cost Analysis Primer for further details on the use of LCCA in the evaluation of alternative infrastructure investments.[12] The Primer demonstrates the value of such analysis in making economically-sound decisions.

2.5.7 Benefit-Cost Analysis Guidance for TIGER and INFRA Applications

The Benefit-Cost Analysis Guidance for TIGER and INFRA Applications combines and expands previous guidance provided for TIGER and FASTLane grant applications.[13] There are several inputs to BCA and this BCA Guide provides default values where appropriate; however, funding programs often require specific values for parameters such as the discount rate, value of statistical life, and value of time. The guidance provides technical information that grant applicants need for monetizing benefits and costs for their (required) project BCA, as well as guidance on BCA approach.

The appendices provide recommended monetary values and sample calculations.(13) One appendix provides supplemental information, standard monetized values (where available), and updates for preparing a BCA. The second appendix provides computational examples and guidance on conducting an analysis. This guidance also refers to the Office of Management and Budget (OMB) Circulars A-4 and A-94 in preparing analyses compliant with federal law.

2.5.8 Highway Safety Improvement Program Manual

The Highway Safety Improvement Program (HSIP) Manual describes the overall program established by FHWA and the methods for developing a roadway safety management program that focuses on results by emphasizing a data-driven, strategic approach to improving highway safety through infrastructure-related improvements.(14) The HSIP Manual describes laws and regulations, new and emerging technologies, and noteworthy practices for each of the HSIP's four basic steps: analyze data, identify potential countermeasures, prioritize and select projects, and determine effectiveness. This reference is intended for State and local transportation safety practitioners working on HSIPs and safety projects. The manual is useful in describing how BCA fits into a transportation agency's overall (federally-mandated) HSIP and the need for BCA in the project prioritization process (Chapter 4 of the HSIP Manual).

2.5.9 Crash Modification Factor Clearinghouse

The BCA Guide and Tool incorporate the use of crash modification factors (CMFs) to estimate safety benefits. The CMF Clearinghouse is a comprehensive and searchable database of published CMFs for hundreds of different types of safety countermeasures.(15) Analysts use CMFs to estimate expected changes in crash frequency and severity from implementing one or more countermeasures. The Clearinghouse contains all CMFs published in the first edition of the Highway Safety Manual as well as many CMFs published or documented in other sources. The Clearinghouse provides information on available CMFs such as the CMF value, general applicability, citation, and quality rating. The Clearinghouse provides links to additional resources to assist CMF Clearinghouse users who are interested in obtaining guidance on other topics related to CMFs such as how to select an appropriate CMF, how to apply CMFs, and how to develop CMFs.

2.6 CHAPTER SUMMARY

Chapter 2 describes fundamental concepts in BCA and safety management. It begins with an overview of BCA and the types of costs (design, construction, operations, and maintenance) and benefits (user benefits and externalities) included in BCA. It describes the safety management process, including two complementary approaches to safety management: crash-based and systemic. Next, the chapter defines several economic measures for use in project decision-making. This is followed by a discussion of the role of BCA in safety management. The chapter concludes with a description of several technical references for conducting highway safety BCA.

Key Takeaways from Chapter 2:

- BCA is a systematic process for calculating and comparing benefits and costs of a project.
- A BCA analyzes project costs (agency costs), project benefits (user benefits), and externalities (non-user benefits) to compare alternatives.
- Project costs include the costs to design, construct, operate, maintain, and rehabilitate the project.
- Project benefits include all benefits to users or society such as reduced crash frequency and severity, reduced travel time and delay, improved travel time reliability, and reduced vehicle operating costs. These can include negative benefits (disbenefits).
- Externalities include reduced air emissions, reduced noise, and reduced impacts to natural habitat and wetlands.
- Safety management includes the identification of opportunities for safety improvement, the implementation of projects to target the identified safety opportunities, and the evaluation of implemented projects to understand the effectiveness of investments.
- A BCA supports decision-making in the safety management and project development process, providing an opportunity to quantify and compare the safety performance and related impacts of alternatives.
- Decision-makers can use BCA to compare the cost-effectiveness of alternatives and identify the most economically-efficient or effective project alternative.
- The BCR and NPV are two common economic measures that incorporate both monetized costs and benefits. The BCR is appropriate to identify the most efficient project alternative. When the budget is fixed (e.g., a set amount of funds is available for systemic improvements), and assuming that funds are expended up to the budget limit, the most efficient project is also the most effective project.
- A BCA is a policy or procedural decision where an agency defines the parameters.

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3. INTRODUCTION TO PROJECT COSTS

FHWA defines project costs as the lifecycle costs of implementing and operating project alternatives.[12] These lifecycle costs represent:

- Initial capital costs of implementing the project, including planning, design, construction/installation, and equipment costs.
- Continuing operations and maintenance costs necessary to keep the project operational, including items such as power, communications, labor, and routine maintenance (excludes replacement costs).
- Replacement cost of equipment that reaches the end of its useful life.
- "End of Project" costs necessary to close temporary projects or any residual or salvage value of equipment at the end of the time horizon of the analysis.

A common error in BCA is underestimating project costs. Analysts should develop a complete, itemized list of initial, continuing, and planned rehabilitation and end-of-life costs. These costs should include all public-sector and private-sector costs as well as contingencies and administrative expenses (e.g., internal staff and overhead costs) as appropriate. If the analyst does not include all major costs in the analysis, then the results may become unreliable and incorrectly favor less efficient alternatives. For example, if the analyst does not consider right-of-way acquisition for the construction of a left-turn lane or the maintenance of a cable median barrier, then these projects may appear much more cost-effective than the agency will realize.

Project costs do not include expenses associated with project financing, such as depreciation and interest payments. The BCA captures the equivalent value of such expenses through the application of the discount rate (Section 5.4) to the project cost. Including depreciation or interest expenses to project costs, in most cases, would double-count costs.

As projects advance through the project development process (e.g., planning to preliminary design to final design), transportation agencies usually refine cost estimates. Agencies can repeat and refine the BCA as better cost estimates become available, given there is value in the results of the BCA. After project implementation, the agency can determine the actual costs and observe the actual benefits. At this point, the agency may complete a final reevaluation of the BCA. This reevaluation may also occur as part of larger program management efforts or when an agency has completed a National Environmental Policy Act (NEPA) analysis (i.e., quantified project externalities). This final evaluation provides insight to more accurately estimate costs and benefits of future projects.

Chapter 3 At-A-Glance

Chapter 3 is divided into five sections:

- Section 3.1 describes initial capital costs.
- Section 3.2 describes continuing operations and maintenance costs.
- Section 3.3 describes rehabilitation and end-of-life costs.
- Section 3.4 identifies data sources for project costs.
- Section 3.5 provides a summary of the chapter.

3.1 INITIAL COSTS

A project's initial costs are those incurred during project development and construction. These costs may include any of the following:

- Planning, preliminary engineering, and assessment.
- Environmental impact reporting.
- Final engineering.
- Right-of-way acquisition.
- Utility impacts (e.g., relocation of power transmission lines).
- Construction of alternative.
- Construction engineering costs.
- Equipment and vehicle purchases.
- Decommissioning costs for existing facilities no longer needed because of the project (e.g., decommissioning of a roadway bridge being replaced by a new bridge facility).

Engineers estimate these costs based on experience, bid prices, design specifications, material costs, and other information. Equipment cost should be assigned to initial costs if the agency does not possess the necessary equipment, but it is required for implementation or maintenance of the project.

Initial costs are costs incurred during project development and construction.

3.2 CONTINUING COSTS

The analyst should obtain, compile, and itemize continuing costs as part of project costs in BCA calculations. Continuing costs include those for preventive activities (e.g., those performed to maintain the project above some predetermined condition or performance level) and day-today routine maintenance intended to address safety and operational concerns. The following are typical elements and examples of these costs:

- Labor, materials, and equipment for operations and maintenance activities.
- Equipment for operation (e.g., wireless transponders for electronic toll collection).
- Utility costs.
- Rent and lease payments.
- Emergency repairs (e.g., replacing damaged guardrail or sign supports).

Continuing costs include the costs for routine operations and maintenance

3.3 REHABILITATION AND END-OF-LIFE COSTS

The analyst should compile and itemize rehabilitation and end-of-life costs to include as a project cost. A project's rehabilitation costs include the future cost of repairs beyond routine maintenance. For example, when a sign reaches the end of its useful life (i.e., retroreflectivity is below the acceptable minimum threshold), then there is a need to replace the sign. This would be considered a rehabilitation cost. Similarly, if the pavement deteriorates along a section of road, there may be a need to rehabilitate the pavement along that section, beyond typical maintenance activities.

Rehabilitation costs include repairs beyond routine maintenance.

End-of-life costs are those costs incurred at the end of a project, or period of analysis. The following are examples of end-of-life costs:

- **Residual value (represented as a negative cost):** The estimated value of project assets at the end of the period of analysis, representing their expected value in continuing use.
- **Salvage value (represented as a negative cost):** The estimated value of an asset in cases where there exists a market for selling the asset.
- **Close-out costs:** Costs incurred at the end of the project's service life or operational period, such as deconstruction costs, assuming the analysis period coincides with the project's operation period.

End-of-life costs include residual and savage values, and close-out costs.

3.4 DATA SOURCES FOR PROJECT COSTS

The analyst can obtain data on project costs from multiple sources within their agency (or from other agencies). Internal sources could be historical records, current bids, agency documents, and engineering judgment (particularly when new materials and techniques are employed). For example, the National Cooperative Highway Research Program (NCHRP) report, Determining Highway Maintenance Costs, presents a process for determining highway maintenance costs.(16) Other resources include the Synthesis of Countermeasure Costs and Service Life and Crash Cost User Guide, which are available on the CMF Clearinghouse.(17,18) The Wisconsin DOT also developed a report, Estimating Cost Per Lane Mile for Routine Highway Operations and Maintenance, to better understand the annual maintenance costs for a wide range of typical highway maintenance activities.(19) Further, many vendors provide cost and service life information for specific products on their website or they will provide quotes upon request.

3.5 CHAPTER SUMMARY

Chapter 3 describes various types of project costs, including the costs to design, construct, operate, maintain, and rehabilitate a project.

Key Takeaways from Chapter 3:

- Initial costs are those incurred during project development and construction (e.g., planning, design, construction/installation, and equipment costs).
- Continuing costs include the costs for routine operations and maintenance (e.g., power, communications, labor, and routine maintenance).
- Rehabilitation costs include the future cost of repairs beyond routine maintenance.
- End-of-life costs are costs incurred at the end of a project, or period of analysis.
- The BCA does not include expenses associated with a project's financing; these values are captured by applying the discount rate to the project cost.
- A common error in BCA is underestimating project costs. An agency can repeat the BCA as better estimates of costs become available.

4. INTRODUCTION TO PROJECT BENEFITS AND EXTERNALITIES

A BCA attempts to capture all benefits to society from a project or course of action. Project benefits (or user benefits) include reductions in crash frequency and severity, travel time and delay, and vehicle operating costs. Externalities (or non-user benefits) include reductions in air emissions, noise, and impacts to natural habitat and wetlands. These benefits and externalities may be a direct benefit from the project or a residual benefit from a reduction in crashes. For example, a signal coordination project may help to improve operations, reducing recurring delay and improving travel time reliability. If this same project reduces crash frequency, then there may be additional operational and environmental benefits from fewer crashes.

Potential benefits include reductions in crash frequency and severity, travel time and delay, vehicle operating costs, and environmental impacts.

It is important to consider all quantitative and qualitative impacts of highway investments. This will help to improve the consistency and reliability of decisions when evaluating and ranking project and program alternatives. This chapter describes the types of project benefits included in a highway safety BCA. The benefits in this Guide focus on the direct and indirect safety impacts, but do not include the direct operational and environmental impacts such as reductions in recurring delay. Direct safety benefits include the expected reduction in crash frequency and severity. Indirect benefits include reductions in travel time, vehicle operating costs, and emissions resulting from fewer crashes. Each section relating to benefits and externalities provides default values to monetize project benefits. Refer to Chapter 7 for practical examples of BCA for safety.

This Guide focus on direct and indirect safety impacts (i.e., expected reduction in crashes and reductions in travel time, vehicle operating costs, and emissions resulting from fewer crashes); it does not include direct operational and environmental impacts such as reductions in recurring delay.

Chapter 4 At-A-Glance

Chapter 4 is divided into six sections:

- Section 4.1 describes direct safety benefits and the associated monetary values, including the value of reducing crash frequency and severity.
- Section 4.2 describes indirect travel time benefits and the associated monetary values resulting from a change in safety performance.
- Section 4.3 describes indirect reliability benefits and the associated monetary values resulting from a change in safety performance
- Section 4.4 describes indirect benefits related to vehicle operating costs and the associated monetary values resulting from a change in safety performance
- Section 4.5 describes indirect emissions benefits and the associated monetary values resulting from a change in safety performance
- Section 4.6 provides a summary of the chapter.

4.1 SAFETY

Safety performance is defined by the estimated long-term average crash frequency and severity. Safety benefits are derived from a change in safety performance (i.e., reduction in the frequency and/or severity of crashes). To monetize safety benefits for a BCA, an analyst multiplies the estimated change in long-term average crashes by the average crash cost.

Safety benefits are derived from an expected change in crash frequency and/or severity.

Section 5.1, *Developing the Project Base Condition*, describes various methods for estimating the safety performance under the base condition (e.g., the do-nothing alternative). Section 6.1, *Estimating Safety Benefits*, describes methods for estimating the expected change in crash frequency by severity. This section describes the use of crash costs in monetizing safety benefits (or disbenefits) and provides default values for use in highway safety BCA.

The FHWA guide, Crash Costs for Highway Safety Analysis, describes methods to estimate crash costs, identifies considerations for applying crash costs in safety analysis, and provides national crash costs to serve as default values for this Guide and the spreadsheet tool.[10] While this Guide provides national default values, it also presents considerations to help determine when it is appropriate to use national or State-specific crash costs as well as information on how to improve the accuracy and consistency of highway safety BCA. The remainder of this section defines key concepts related to crash costs, describes general considerations for applying crash costs, and finally presents default crash cost values. Refer to the FHWA guide, Crash Costs for Highway Safety Analysis, for further details.[10]

Crash costs may represent economic costs or comprehensive costs. Economic costs (or human capital costs) are the monetary impacts of crashes, including costs related to crash response, property damage, and medical treatment. Economic costs include the following components:

- Emergency services provided by police, emergency medical services (EMS), fire services, and incident management services at the scene of the crash.
- Medical services provided in the emergency rooms, in hospitals as inpatients and outpatients, out of hospital costs (e.g., physical therapy, rehabilitation, prescriptions, prosthetic devices, home modifications), and coroner services in the event of fatal injuries. Some studies include EMS costs within medical costs.
- Household productivity loss due to the lost ability to perform one's normal household responsibilities (i.e., related to the injured or killed victims and other family members caring for the crash victim), equivalent to the present value of hiring a person to accomplish the same tasks.
- Market productivity loss due to lost wages and fringe benefits over the victim's remaining life span, expressed in present value.
- Insurance administration to process insurance claims (e.g., medical expenses, liability, disability, worker's compensation, welfare payments, sick leave, property damage, life insurance) resulting from crashes, and the cost of defense attorneys.
- Workplace costs due to an employee's absence (e.g., new employee retraining, overtime to accomplish work of the injured employee, administration of processing personnel changes).
- Legal costs due to fees and operating courts during civil litigation resulting from the crashes.
- Congestion impacts due to travel delay to those not involved in the crashes, added fuel consumption, and increased pollution.
- Property damage to vehicles, cargo, roadways, and roadside furniture.

Comprehensive crash costs (or societal crash costs) capture all impacts resulting from crashes and are generally most appropriate for monetizing the value of crashes. Comprehensive crash costs are the combination of economic costs and the monetized value of intangible impacts (i.e., the valuation of loss of life for a fatal injury or loss in quality-of-life for a non-fatal injury). The value of a statistical life (VSL) represents the cost corresponding to the prevention of one fatality. The intangible consequences due to a non-fatal injury are referred to as the lost quality-of-life, monetized as quality-adjusted life years (QALY). QALY costs are determined by the duration and severity of the health problem.

Comprehensive crash costs are generally most appropriate for monetizing the value of crashes.

Crash costs are commonly developed and presented by severity for a specific injury scale (e.g., KABCO or Abbreviated Injury Scale (AIS)). KABCO is defined in the Model Minimum Uniform Crash Criteria (MMUCC), a standardized set of data elements and attributes for crash reporting. MMUCC 5th Edition provides the following definitions:[20]

Fatal Injury (K): A fatal injury is any injury that results in death within 30 days after the motor vehicle crash in which the injury occurred. If the person did not die at the scene but died within 30 days of the motor vehicle crash in which the injury occurred, the injury classification should be changed from the attribute previously assigned to the attribute "Fatal Injury."

Suspected Serious Injury (A): A suspected serious injury is any injury other than fatal which results in one or more of the following:

- Severe laceration resulting in exposure of underlying tissues/muscle/organs or resulting in significant loss of blood.
- Broken or distorted extremity (arm or leg).
- Crush injuries.
- Suspected skull, chest or abdominal injury other than bruises or minor lacerations.
- Significant burns (second and third degree burns over 10% or more of the body).
- Unconsciousness when taken from the crash scene.
- Paralysis.

Suspected Minor Injury (B): A minor injury is any injury that is evident at the scene of the crash, other than fatal or serious injuries. Examples include lump on the head, abrasions, bruises, minor lacerations (cuts on the skin surface with minimal bleeding and no exposure of deeper tissue/muscle).

Possible Injury (C): A possible injury is any injury reported or claimed which is not a fatal, suspected serious, or suspected minor injury. Examples include momentary loss of consciousness, claim of injury, limping, or complaint of pain or nausea. Possible injuries are those which are reported by the person or are indicated by his/her behavior, but no wounds or injuries are readily evident.

No Apparent Injury (O): No apparent injury is a situation where there is no reason to believe that the person received any bodily harm from the motor vehicle crash.

There is no physical evidence of injury and the person does not report any change in normal function.

The "O" code is also often called property damage only (PDO), indicating property damage was the highest severity impact of the crash. Some States include a "U" code, which may indicate either an injury of unknown severity or it is unknown if there was an injury in the crash, depending on the State and definition.

AIS is an integer scale developed by the Association for the Advancement of Automotive Medicine to rate the severity of individual injuries. AIS includes current medical terminology, providing an internationally-accepted and anatomically-based tool for ranking injury severity.[21] Table 7 presents the six-point AIS scale to classify individual injuries, where 1 indicates very minor injury and 6 indicates currently untreatable injuries. A value of 0 indicates no injury, while a value of 9 indicates the injury level is unknown or not classifiable.

Table 7. AIS injury codes.[21]

AIS Code	Injury	Example	Probability of Death (%)
0	None	No injury	0
1	Minor	Superficial laceration	0
2	Moderate	Fractured sternum	1 – 2
3	Serious	Open humerus fracture	8 – 10
4	Severe	Perforated trachea	5 – 50
5	Critical	Ruptured liver with tissue loss	5 – 50
6	Maximum	Total severance of aorta	100
9	Not further specified	N/A	N/A

It is important to understand the differences between injury scales because crash costs reflect one scale or the other and may represent either crash-level costs or person-level costs. Police typically use the KABCO scale to report the injury severity for each person involved in a crash (i.e., person-level injury). The crash-level severity is defined by the most severe person-level injury associated with the crash. Hospitals and motor vehicle crash investigators (e.g., NHTSA, Insurance Institute for Highway Safety) use the AIS scale. The AIS scale represents person-level injuries, and the Modified Abbreviated Injury Scale (MAIS) is the score of the most severe injury suffered by an injured person in a crash. Translator tables allow analysts to convert between the KABCO and AIS scales as well as convert between crash-level and person-level costs.

Table 8 presents a list of frequently asked questions and answers for applying crash costs.

Table 8. Frequently asked questions and answers for applying crash costs.

Question	Answer
Is it more appropriate to use economic or comprehensive crash costs?	It is typically more appropriate to use comprehensive crash costs in highway safety BCA to account for both the economic costs and intangible costs (e.g., pain and suffering).
Is it necessary to convert between KABCO and MAIS injury scales?	It is necessary to convert between KABCO and MAIS injury scales when developing crash costs or when the crash data and crash costs reflect different injury scales. Translator tables are available to convert between the KABCO and MAIS injury scales if needed. For highway safety BCA, the crash data typically reflect the crash-level KABCO scale, which is the same level as the average crash costs in Table 9. In this case, there is no need to convert between KABCO and MAIS. Refer to the FHWA guide, Crash Costs for Highway Safety Analysis, for details on how to convert between the two scales.(10)
Is it necessary to convert between crash-level and person-level injury costs?	Crash-level costs should be applied to the number of crashes and person-level costs should be applied to the number of involved-persons in crashes. It is necessary to convert between crash-level and person-level injury costs when the available crash costs do not reflect the desired level of analysis.
Is it appropriate to apply crash costs by crash type and severity?	Applying crash costs by both crash type and severity provides arguably the most accurate estimates for BCA; however, there are practical limitations. First, it is necessary to estimate the expected change in crashes by type and severity, which may not be possible given the current state-of-the-knowledge. Second, crash costs are typically developed by crash severity (and not by type). In the absence of reliable estimates by crash type and severity, it is appropriate to apply crash costs by severity. This helps to account for situations when a countermeasure contributes to different effects by crash severity. For example, replacing a two-way stop-controlled intersection with a traffic signal may increase PDO and minor injury crashes while reducing fatal and serious injury crashes. When estimating the change in crashes by severity, the analyst can then apply crash costs by severity to reflect the difference in cost by severity. The analyst can then aggregate the crash costs among the severity levels to monetize the safety benefit of the alternative in question.

QUESTION	ANSWER
Is it appropriate to use weighted crash costs?	Unweighted crash costs by injury severity place a high cost on fatal and serious injury crashes and related injuries, which can skew the results of highway safety BCA, particularly when analysts use the observed crash history to estimate the long-term average safety performance. Analysts should strive to estimate the long-term safety performance using predicted or expected crash frequency rather than observed crash frequency. Analysts can then apply unweighted crash costs to these estimates. Weighted costs (e.g., combining K/A or A/B/C costs) help to offset the impact of higher severity crashes in BCA, but also increase the impact of lower severity crashes in BCA. While not the preferred practice, if an analyst uses observed crash frequency in highway safety BCA, weighted crash costs can help to overcome some limitations. To develop weighted crash costs, it is suggested to use the severity distribution from the jurisdiction to which the weighted costs will be applied. Refer to the FHWA guide, Crash Costs for Highway Safety Analysis, for details on how to develop weighted crash costs.(10)
Is it necessary to adjust national crash costs to reflect State-specific costs and injury levels?	It is appropriate to adjust national crash cost estimates to State-specific estimates when possible. The primary difference in crash costs among States is based on differences in cost of living, income, and medical costs. Analysts can use per capita income (PCI) to adjust crash-level costs and person-level costs. Specifically, the analyst would multiply the crash cost by the ratio of the State's PCI to the national PCI. Given person-level crash costs, it is appropriate to adjust for differences in severity distributions among States as this affects aggregated crash-level costs developed from person-level costs. Specifically, it is necessary to account for a State's person-to-crash ratio and severity distribution when converting person-level costs from national sources or from one State to another State. Refer to the FHWA guide, Crash Costs for Highway Safety Analysis, for details on how to account for State-specific ratios and severity distributions.(10)

Analysts should estimate safety performance using predicted or expected rather than observed crash frequency.

4.1.1 Value of Crashes

Table 9 provides national default comprehensive crash cost values in 2017 dollars. Again, refer to the FHWA guide, Crash Costs for Highway Safety Analysis, for further background and procedures to adjust these national default costs to reflect current year and State-specific costs.[10]

Table 9. Comprehensive crash costs (2017 U.S. $).

Severity	Comprehensive Crash-Level Cost
K	$11,637,947
A	$674,353
B	$204,143
C	$129,001
O	$12,108

4.1.2 Data Sources for Safety

Crash data and traffic volume data are typically required for a rigorous BCA. As will be discussed in chapter 5 and chapter 6, these data support the estimation of the safety performance for the base condition (e.g., the do-nothing alternative) and the estimation of the change in safety performance with a given alternative. Analysts can generally obtain crash and traffic volume data from the State or local transportation agency for which the BCA is being conducted. In some cases, it may be necessary to request crash data from the State department of motor vehicles.

4.2 TRAVEL TIME

User travel time represents the sum of all person hours of travel (PHT). To incorporate travel time benefits in BCA, it is necessary to estimate the net change in travel time resulting from implementation of a project within the defined geographic scope of the analysis. The BCA may differentiate recurring delay and nonrecurring delay, and it may estimate PHT separately for different modes and vehicle types. Generally, the calculation differentiates truck travel time from auto and transit travel time due to the higher costs associated with truck travel time.

While BCA commonly incorporates user travel time related to recurring delay as a benefit, it is also important to consider the indirect safety benefits of projects (i.e., impacts of reductions in crashes on nonrecurring delay). Specifically, reductions in crash frequency and severity help to reduce user travel time by reducing nonrecurring delay. If a project reduces nonrecurring delay, particularly for crashes, then only considering the benefit of recurring delay will result in an understatement of benefits. Some projects have no impact on travel time and recurring delay (e.g., installing chevrons along a horizontal curve), while other projects make traffic flow more uniform and thereby enhance mobility by decreasing travel times (e.g., signal coordination). Some projects may also increase travel time and delay while improving safety. For example, consider the impacts of implementing protected left-turn phasing at a signalized intersection. Protected left-turn phasing may reduce the frequency and severity of crashes, improving reliability by reducing nonrecurring delay; however, this can increase the recurring delay.

This Guide focuses on travel time and delay reductions that result from crash reductions. Analysts should seek other data and tools to estimate direct travel time and delay benefits.

The method for estimating the net change in user travel time can range from simple estimations, to complex analyses involving models to calculate the expected changes in transportation system demand and performance. The method and tools analysts use to estimate travel time savings should be scaled to the level of detail needed for the analysis. At the simplest level, the BCA can estimate changes in user travel time by applying a factor representing the anticipated impact of the strategy to the base condition (forecast future travel times with and without construction of the alternatives). Section 6.2, *Estimating Travel Time Benefits*, describes a more advanced method for estimating the travel time benefits based on the expected change in crash frequency. The remainder of this section presents values to convert travel time savings to monetary benefits.

4.2.1 Value of Time

The NHTSA report, *The Economic and Societal Impact of Motor Vehicle Crashes*, provides monetized values of time by roadway facility type.[11] Table 10 presents the NHTSA value of time, which is used in the examples throughout this Guide, for five facility types, converted to 2017 dollars using the Consumer Price Index (CPI). The average values of time in the second column of the table are based on the separate values of time for passenger travel and truck travel as well as the assumed percent cars and percent trucks shown in the last four columns. These values are based on a study by the Federal Motor Carrier Safety Administration, which is referenced in the NHTSA report.[22] The BCA Tool that complements this Guide provides options for the user to update the values of time and percentage of cars and trucks to reflect local conditions.

Table 10. NHTSA recommended values of travel time (2017 U.S. $)[11]

Road Type	Average Value of Time (per person-hour)	Value of Time for Passenger Vehicles	Value of Time for Trucks	Percent Cars	Percent Trucks
Urban Interstate / Expressway	$27.01	$26.01	$38.61	92%	8%
Urban Arterial	$26.60	$26.06	$36.90	95%	5%
Urban Other	$26.58	$26.20	$35.83	96%	4%
Rural Interstate / Principal Arterial	$28.98	$26.25	$39.90	80%	20%
Rural Other	$27.57	$26.58	$37.49	91%	9%

Depending on the benefit valuation scheme, and the rigor of the BCA, the analyst may segment the net change in PHT by trip purpose. The following are typical options for segmenting by trip purpose:

- **On-the-clock travel:** Represents people traveling for business purposes during work hours (e.g., a plumber traveling to the next work site).
- **Commuter travel:** Represents individuals traveling between home and job location.
- **Nonwork travel:** Represents individuals traveling for shopping, school, recreation, or other purposes.

The reason for differentiating trip purposes is to apply different values of travel time based on the nature of the trip. A BCA may include a higher value for travel time incurred during on-the-clock travel than for non-work travel, due to the greater direct costs incurred in any delay in on-the-clock travel.

Table 11 presents the value of time monetization factors by type of travel from the TIGER Resource guide.[23] These factors apply to surface modes except high-speed rail. While this Guide uses the NHTSA-recommended values in Table 10, the analyst may decide to use the values in Table 11 when considering the impacts by type of travel. These are more applicable to analyses of recurring delay that include breakdowns of travel time by type of travel.

Table 11. TIGER recommended values of travel time by type (2017 U.S. $).[(23)]

Type of Travel	Value of Time for Local Travel (per person-hour)	Value of Time for Intercity Travel (per person-hour)
Personal*	$13.18	$18.45
Business	$25.73	$25.73
All Purposes**	$13.71	$20.04

* Applies to all combinations of in-vehicle and other transit time. Walk access, waiting, and transfer time in personal travel should be valued at $24.97 per hour for personal travel when actions affect only those elements of travel time.

** These are weighted averages, using distributions of travel by trip purpose on various modes. Distribution for local travel by surface modes: 95.4% personal, 4.6% business. Distribution for intercity travel by conventional surface modes: 78.6% personal, 21.4% business. Figures derived using annual person-miles of travel (PMT) data from the 2001 National Household Travel Survey. http://nhts.ornl.gov/.

Note: Monetary values indexed from 2013 to 2017 dollars using the Bureau of Labor Statistics CPI Inflation Calculator Tool.

Table 12 presents the value of time monetization factors for specific types of drivers from the TIGER Resource guide.[(23)] Again, while this Guide uses the NHTSA-recommended values in Table 10, the analyst may decide to use the values in Table 12 when considering the impacts by type of driver. These are more applicable to analyses of recurring delay that include breakdowns of travel time by mode, which correlates to type of driver.

Table 12. TIGER recommended values of driver time (2017 U.S. $).[(23)]

Type of Driver	Value of Time (per person-hour)
Truck Drivers	$27.21
Bus Drivers	$28.16
Transit Rail Operators	$48.83
Locomotive Engineers	$40.81
Airline Pilots and Engineers	$88.79

Note: Monetary values indexed from 2013 to 2017 dollars using the Bureau of Labor Statistics CPI Inflation Calculator Tool.

The NHTSA- and TIGER-recommended value of time estimates are based on different methods, hence the differences in values. The NHTSA values are based on guidance issued by the USDOT regarding the valuation of travel time and are provided by facility type.[(24)] The TIGER guidance monetizes the value of time under various surface modes for both business and personal travel, valuing business travel by wage rates and personal travel by a variable percentage of wage rates, depending on mode and whether travel is local or intercity.

The value of time selected should match the data source for time savings. If the data reflect time savings by facility type, then the values from Table 10 are appropriate. If the data reflect time savings by type of travel or type of driver, then values from Table 11 or Table 12 are appropriate. These estimates also change over time, so analysts should use the most recent values.

The value of time should match the data source for time savings.

This Guide uses the NHTSA monetized values of time, converted to 2017 dollars (Table 10). The NHTSA value of time estimates are intended specifically for monetizing the travel time benefits related to crash reductions. Further, the NHTSA values provide detail by facility type and crash severity. The values from the TIGER and INFRA guidance are intended for a much broader set of project types across all modes. Again, the NHTSA method only considers the direct and indirect benefits related to crash reductions. Projects may provide other direct benefits such as capacity expansion, access, and goods movement. As such, the analyst should seek other data and tools to estimate these additional direct benefits as needed.

NHTSA monetized values of time are used in this Guide and Tool to monetize travel time benefits related to crash reductions.

4.2.2 Data Sources for Travel Time

The value of time is often estimated through stated preference or revealed preference surveys. Stated preference (sometimes referred to as contingent valuation) is a survey-based technique for establishing valuations for a subject of interest such as time saved. The traveler is asked how much they value time, that is, what would they be willing to pay to avoid the loss of time caused by congestion. Surveys identify preferences for time savings by studying the actual decisions people make, such as the willingness to pay a toll to decrease travel time. These revealed behaviors may be very different from stated preferences.[25] The value of time may vary based on region or circumstances of the traveler (e.g., mode and purpose of travel). As such, agencies may choose to conduct surveys to estimate a local value of time instead of using national values.

4.3 TRAVEL TIME RELIABILITY

Transportation officials have increasingly recognized the importance of travel time reliability when evaluating transportation projects. Historically, average travel time was the primary measure used for BCA of transportation projects. However, use of this average measure only captures the change in recurring travel time. As shown in Figure 5, the use of average travel time may not realistically represent actual travelers' experiences.

Average travel time may not realistically represent actual travelers' experiences.

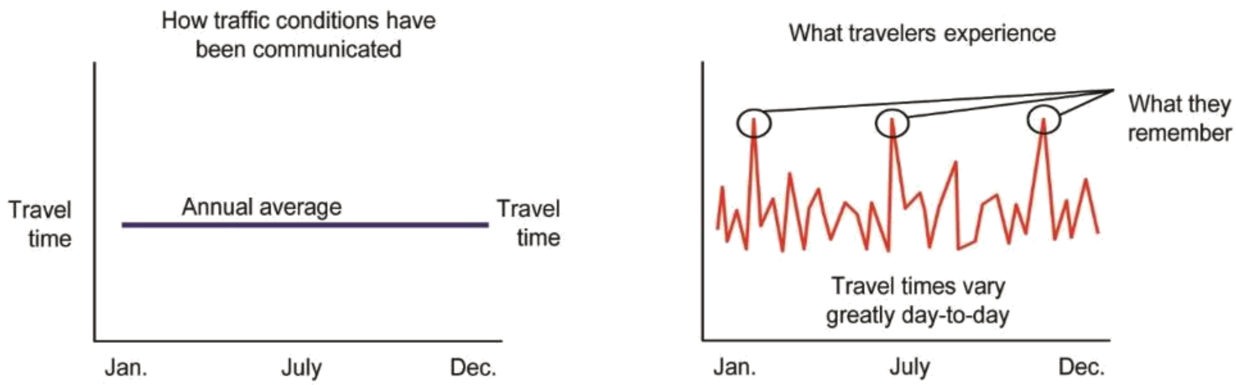

Figure 5. Chart. Recurring travel time measurement versus actual traveler experience.[26]

Significant research and analyses have been performed on the effects of nonrecurring travel time delay caused by factors such as crashes, special events, weather, and construction work zones. Research completed as part of the Transportation Research Board's (TRB) Second Strategic Highway Research Program (SHRP2) and other Federal and State efforts have shown the amount of delay caused by nonrecurring congestion is substantial. Omitting this measure from transportation BCA may severely understate potential project benefits. This section describes several methods for evaluating travel time reliability.

Travel time reliability measurement seeks to quantify the variability in travel times caused by nonrecurring and recurring congestion sources to better estimate the full distribution of travel times experienced by the system users. Transportation researchers have developed several performance measures and indices to help quantify reliability impacts.

Table 13 briefly defines each reliability measure and Figure 6 provides an example graphic to illustrate these measures empirically. Many of these measures are based on an analysis of the distribution of travel times for a segment or facility. For some measures, there are multiple definitions based on SHRP2 reliability research.[27] For example, the Planning Time Index and Buffer Index are best estimated using the median travel time; however, median travel time may not be readily available. In such cases, the analyst may need to substitute average travel time for median travel time. The Failure/On-Time metrics may be based on either travel time or speed brackets. Either may be appropriate, depending on the data available.

This Guide uses buffer time to estimate the impact of crash reductions (or increases) on reliability. Buffer time is the amount of extra time that most travelers add to their average travel time to ensure a certain level of on-time arrival. Figure 6 shows buffer time as the difference between the mean travel time (TT_m) and the travel time at 95 percent on-time arrival assurance (TT_{95}). Whether expressed as a percentage or in minutes, it represents the extra time a traveler should allow to arrive on-time for 95 percent of all trips. A simple analogy is that a traveler who uses a 95 percent reliability indicator would be late only one weekday per month. The standard deviation of travel time approximates the mean buffer time travelers would need to meet their individual on-time requirements given their experience with the network performance. As such, the change in the standard deviation of travel time approximates the change in the mean buffer time.

Table 13. Reliability performance measures.[27]

Performance Metric	Definition	Units
Planning-Time Index	• 95th percentile Travel Time Index (95th percentile travel-time divided by the free-flow travel time), normalized by the average travel time. • The difference between the 95th percentile travel time and the median travel time, normalized by the median travel time.	None
Buffer Index (BI)	• The difference between the 95th percentile travel time and the average travel time, normalized by the average travel time, often shown for 80%, 85%, or 90% as well. • The difference between the 95th percentile travel time and the median travel time, normalized by the median travel time, often shown for 80%, 85%, or 90% as well.	Percent
Failure/On-Time Measures	• Percent of trips with travel times less than 1.1 * Median Travel Time or 1.25 * Median Travel Time. • Percent of trips with space mean speed less than 50 mph, 45 mph, or 30 mph.	Percent
80th Percentile Travel-Time Index	• 80th percentile travel time divided by the free-flow travel time.	None
Skew Statistic	• The ratio of (90th percentile travel time minus the median) divided by (the median minus the 10th percentile).	None
Misery Index (Modified)	• The average of the highest five percent of travel times divided by the free-flow travel time.	None

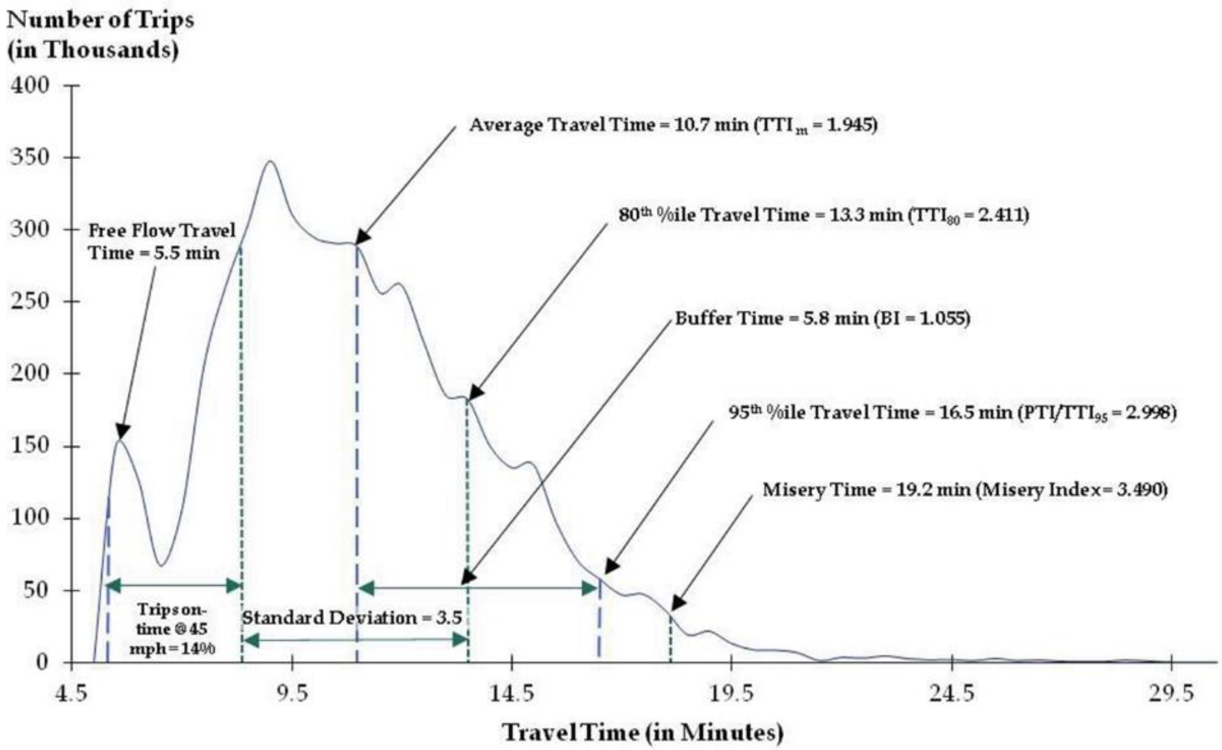

Figure 6. Chart. Relationship of travel time measures and reliability.[(28)]

This Guide and Tool use buffer time to estimate the impact of crash reductions (or increases) on reliability.

4.3.1 Value of Travel Time Reliability

Projects that improve safety also improve reliability by reducing the number and severity of crashes. To the extent that crash reductions improve network performance, travelers can reduce the buffer time, realizing benefits related to time savings. To monetize estimates of travel time reliability, a value of time measure is applied to the travel time reliability savings measure. The analyst can monetize the time savings using the preferred value of time (either local value of time or national values such as those in Table 10).

This type of analysis applies to the evaluation of travel time reliability for existing transportation facilities. This method is not as useful as a predictive tool. Further, sufficient data are required to support the estimation of the travel time distributions. In addition, transportation projects may have a direct benefit on travel time reliability, beyond the indirect benefit of crash reductions. As such, the analyst should seek to estimate and include these additional direct benefits in the BCA as needed.

Transportation projects may have a direct benefit on travel time reliability, beyond the indirect benefit of crash reductions or increases.

4.3.2 Data Sources for Travel Time Reliability

Travel time distributions are obtained from modern real-time vehicle to infrastructure (V2I) travel data collection, long-term data archive systems, multiple manual data collection and monitoring activities, or modeling efforts using multiple scenarios representing expected traffic conditions. The analyst then multiplies the net change in the standard deviation in minutes of travel time by the number of facility users. This calculation provides a temporal measure of travel time reliability savings which can be monetized in a BCA.

The analyst should ensure that the dataset used to estimate the distribution of travel times is sufficiently robust to capture travel times during a representative sampling of conditions. This may require six months, for relatively simple cases, to multiple years' worth of continuous data, where an elevated level of confidence in analysis results is required. For a BCA, the analyst should consider the overall project budget and level of effort desired before undertaking a travel time reliability study that involves months or years of effort.

4.4 VEHICLE OPERATING COSTS

Change in net vehicle operating cost is a common measure used for transportation projects. A BCA typically breaks out vehicle operating cost into fuel use and nonfuel use categories; although, they may be combined as a single measure. Nonfuel use costs typically include vehicle maintenance, insurance, and depreciation, but do not include vehicle registration and taxes because economists consider these transfers. Benefits attributable to lower vehicle operating cost are usually not a major component of a project's overall benefit.

Estimation of vehicle operating cost is often based on simple valuations applied directly to vehicle miles traveled (VMT). Any net change in total VMT or roadway speed attributable to a project alternative will affect fuel use. For simple analysis, the BCA applies a static rate of average fuel use (gallons per VMT) to any net change in VMT to estimate the net change in fuel use. The BCA then applies a benefit value (cost per gallon of fuel exclusive of fuel taxes) to the change in the number of gallons of fuel consumed. The federal government anticipates future year vehicle fleets to have greatly improved fuel use rates. Since estimated fuel use rates can differ substantially based upon the year of analysis, practitioners are encouraged to use fuel rates appropriate to that year.[29]

For nonfuel operating costs (e.g., maintenance, tires, tolls, lease, and financing), the BCA can estimate the benefit values through VMT and change in VMT. Like fuel use rates, this benefit value may be sensitive to the forecast year of analysis; however, nonfuel vehicle operating costs are usually not sensitive to differences in operating conditions (e.g., travel speeds).

For highway safety BCA, it is necessary to relate the change in safety performance to a change in fuel use as the project may or may not impact VMT. The NHTSA report, *The Economic and Societal Impact of Motor Vehicle Crashes*, provides values of increased fuel use per crash by crash severity and roadway facility type.[11] Chapter 6 provides further details on applying this method.

This Guide focuses on reductions in fuel use that result from crash reductions.

4.4.1 Value of Vehicle Operating Costs

To monetize fuel-related benefits, apply the cost per gallon of fuel, exclusive of fuel taxes, to the change in fuel use. Analysts can obtain estimates of fuel costs from websites such as the US Energy Information Administration.[30]

To monetize nonfuel vehicle-use benefits, apply the average vehicle operating cost per mile to the change in VMT. This Guide does not include nonfuel vehicle-use benefits in the highway safety BCA because most safety projects do not impact the VMT. Specifically, there is limited or no induced demand so the expected change in VMT would be the same for the base and alternative conditions.

The vehicle operating cost per mile varies by type and age of vehicle. Even within light duty vehicles, there are substantial variations in vehicle operating cost per mile due to differences in vehicle weight, design, fuel type, and other factors. The Benefit-Cost Analysis Guidance for TIGER and INFRA Applications recommends a 2016 value of $0.40 per mile for light duty vehicles and $0.96 per mile for heavy duty vehicles. The light duty vehicle operating cost is based on an average sedan and costs such as gasoline, maintenance, tires, and depreciation, assuming an average of 15,000 miles driven per year. The value omits other ownership costs that are mostly fixed or transfers (insurance, license, registration, taxes, and financing charges). The heavy-duty vehicle operating cost includes fuel costs, truck/trailer lease or purchase payments, repair and maintenance, truck insurance premiums, permits and licenses, and tires. The value omits tolls (transfers) and driver wages and benefits, which are included in the value of travel time savings.

4.4.2 Data Sources for Vehicle Operating Costs

The Benefit-Cost Analysis Guidance for TIGER and INFRA Applications is updated periodically providing the latest USDOT-approved values for vehicle operating cost. The 2017 version provides 2016 values based on data from the following sources:

- American Automobile Association, Your Driving Costs – 2016 Edition (2016), http://exchange.aaa.com/automotive/driving-costs/#.WVZdF02oupp.(31)
- American Transportation Research Institute, An Analysis of the Operational Costs of Trucking: 2016 Update (2016), http://atri-online.org/wp-content/uploads/2016/10/ATRI-Operational-Costs-of-Trucking-2016-09-2016.pdf.(32)

These values are updated annually, which is typically more frequent than the USDOT BCA guidance. The analyst can use the source information or use the CPI to update the DOT values between publication years.(33) For example, to update 2016 values to 2017, multiply by 1.6154 (i.e., 2.1 percent average annual CPI in 2017 divided by 1.3 percent average annual CPI in 2016).

4.5 EXTERNALITIES

One of the more challenging areas of BCA is the treatment and valuation of externalities (non-user costs) related to transportation projects. Economists define an externality as the uncompensated impact of one person's actions on the well-being of a bystander. In the case of transportation investments, "bystanders" are the non-users of the project.

Externalities include uncompensated impacts on bystanders.

Examples of externalities include the following:

- Changes in air emissions (e.g., criteria pollutants regulated by the Clean Air Act).
- Noise impact (i.e., increases or decreases in noise levels).
- Construction impacts (e.g., degradation in roadway level of service on surrounding neighborhoods).
- Impacts to natural habitats, wetlands, and streams.
- Permanent property value impacts.

When the impact benefits the non-user, economists refer to it as a positive externality. When the impact is adverse, economists refer to it as a negative externality. Often, the BCA focuses on negative externalities. Negative externalities include the undesirable effects of a project on air and water quality, noise and construction disruptions, and other community or aesthetic impacts as described. Positive externalities, however, also exist. For example, a project may serve to reduce air or noise pollution from previously existing or projected levels.

Transportation agencies generally analyze a project's environmental impact (including externalities) through environmental studies required by the NEPA as well as other State and local environmental compliance laws. This is particularly the case for larger projects where the agency must prepare an Environmental Impact Statement (EIS) or Environmental Assessment (EA). The EIS or EA generally quantifies the project's impact to air quality, noise levels, and the natural environment such as loss of wetlands or habitat for threatened and endangered species.

Analysts can use NEPA studies to quantify the impact of externalities for use in a BCA. Transportation agencies should closely coordinate NEPA studies and BCA to the extent possible. Where possible, the analyst should utilize the analysis completed through the NEPA process to evaluate the cost to mitigate natural environmental impacts (e.g., wetland or habitat loss). Analysts may also use environmental impacts described in the NEPA study to qualitatively evaluate and compare alternatives. The BCA can utilize broader impact estimates to more accurately estimate project costs and benefits (e.g., estimates of air quality impacts from a larger program of safety improvements implemented on a statewide level).

Analysts can use the results of NEPA studies to quantify the impact of externalities for use in a BCA.

Emissions are a common externality monetized for transportation projects. The inclusion of emissions estimates in BCA is particularly important when transportation agencies prioritize projects in competition for several types of funding (e.g., Safety, Operations, or Congestion Mitigation, and Air Quality (CMAQ) funds), or the project is considered in an air quality nonattainment area.

The Clean Air Act requires the Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards (40 CFR part 50) for pollutants considered harmful to public health and the environment. The Clean Air Act identifies two types of national ambient air quality standards: primary and secondary. Primary standards provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.

The EPA has set National Ambient Air Quality Standards for six principal pollutants, which are called "criteria" air pollutants. Periodically, the standards are reviewed and revised. The current standards are listed below. A BCA often includes one or more of these pollutants depending on the concerns of the local region. Units of measure for the standards are parts per million (ppm) by volume, parts per billion (ppb) by volume, and micrograms per cubic meter of air ($\mu g/m^3$).

- Hydrocarbons (HC)/Reactive Organic Gases (ROG).
- Nitrous Oxide (NOx).
- Carbon Monoxide (CO).
- Carbon Dioxide (CO2).
- Particulate Matter (PM10) or Fine Particulate Matter (PM2.5).
- Sulfur Dioxide (SO2).

4.5.1 Value of Emissions

The NHTSA report, *The Economic and Societal Impact of Motor Vehicle Crashes*, provides monetized values for select emissions per crash by crash severity and roadway facility type.[11] These emissions include volatile organic compounds (VOCs), but do not include PM10 or CO. PM10 is not included because virtually all the adverse health impacts from PM arise from fine particulates, defined as the fraction that is less than 2.5 microns in diameter (hence the notation PM2.5). CO is not included because at current exposure levels, there is no evidence that CO causes any adverse health impacts. Table 14 through Table 16 present the NHTSA-developed emissions values for five facility types, converted to 2017 dollars using the CPI.

This Guide focuses on emissions reductions that result from crash reductions. Analysts should seek other data and tools to estimate direct emissions benefits.

Table 14. Estimated value of net emissions per fatal crash (2017 dollars).[11]

Facility Type	CO_2	NO_X	$PM_{2.5}$	SO_2	VOC	Total Emissions
Urban Interstate / Expressway	$827.90	$197.59	$895.53	$70.79	$23.61	**$2,015.41**
Urban Arterial	$213.66	$50.27	$133.83	$18.09	$3.99	**$419.84**
Urban Other	$16.37	$3.95	$8.92	$1.41	$0.27	**$30.92**
Rural Interstate / Principal Arterials	$124.60	$59.72	$178.65	$10.38	$2.44	**$375.79**
Rural Other	$15.47	$6.28	$17.54	$1.28	$0.28	**$40.84**
Average for All Road Types	$159.48	$44.36	$159.17	$13.53	$3.82	**$380.36**

Table 15. Estimated value of net emissions per injury crash (2017 dollars).[11]

Facility Type	CO_2	NO_X	$PM_{2.5}$	SO_2	VOC	Total Emissions
Urban Interstate / Expressway	$174.91	$41.74	$189.15	$14.98	$4.99	**$425.77**
Urban Arterial	$47.38	$11.14	$29.16	$4.02	$0.88	**$92.57**
Urban Other	$7.18	$1.72	$3.76	$0.62	$0.12	**$13.41**
Rural Interstate / Principal Arterials	$22.98	$11.02	$33.05	$1.94	$0.45	**$69.43**
Rural Other	$3.93	$1.59	$4.38	$0.32	$0.07	**$10.29**
Average for All Road Types	$34.29	$9.40	$33.45	$2.92	$0.81	**$80.87**

Table 16. Estimated value of net emissions per PDO crash (2017 dollars).[11]

Facility Type	CO_2	NO_X	$PM_{2.5}$	SO_2	VOC	Total Emissions
Urban Interstate / Expressway	$148.76	$35.51	$160.61	$12.67	$4.24	**$361.79**
Urban Arterial	$28.71	$6.75	$18.34	$2.41	$0.53	**$56.75**
Urban Other	$4.33	$1.05	$2.25	$0.36	$0.08	**$8.06**
Rural Interstate / Principal Arterials	$23.38	$11.21	$33.38	$1.91	$0.46	**$70.34**
Rural Other	$3.28	$1.34	$3.59	$0.28	$0.06	**$8.55**
Average for All Road Types	$27.16	$7.70	$27.85	$2.29	$0.66	**$65.67**

When an agency cannot quantify the dollar value of an externality, they may choose to deal with it on an as-needed qualitative basis. If the measurable net benefits of a project are highly positive, decision makers may tolerate minor unquantified externalities from an economic standpoint, even if the agency perceives the externalities to be negative. On the other hand, if the net benefits are very low, then the existence of significant unquantified negative externalities may tip the economic balance against the project. An example of this could include negative impacts to low-income and minority populations that live near the project location. The project could impact these populations through increases in air pollution, noise, or traffic.

Analysts may deal with externalities on a qualitative basis if they cannot quantify the dollar value.

It may not be easy to monetize quality of life measures or other potentially controversial measures. The BCA can include such items through qualitative presentations. These types of externalities become important if the monetized present value of benefits do not exceed or only barely exceed the monetized present value of costs.

4.5.2 Data Sources for Emissions

Emissions may represent one of the most complex measures to estimate in BCA. This is due to the many variables that determine the appropriate emission rates. Most emissions estimations are based on an application of an emissions rate on a per VMT basis. Depending on the emissions category, the appropriate emissions rate to apply may be sensitive to numerous factors, including the following:

- Year of the analysis (i.e., the EPA anticipates future year vehicle fleets to produce fewer emissions in many categories).
- The mix of gasoline and diesel vehicles in the regional fleet.
- Vehicle speeds.
- The number of cold starts.
- The mix of vehicles in the regional vehicle mix (e.g., autos, light trucks, medium-duty trucks, heavy-duty trucks, etc.).
- Regional weather patterns/climate and other considerations.

Given these many variables impacting emissions rates, analysts should obtain rates using existing emissions analysis tools, calibrated to the individual region or derived from previously conducted regional analysis. Therefore, analysts should use caution when applying emissions rates derived from other regions or based on averages among different regions. This Guide does not provide detailed estimates of emissions rates by region, but does provide a method for quantifying and monetizing emissions based on the expected change in crashes (refer to Chapter 6).

4.6 CHAPTER SUMMARY

Chapter 4 describes various types of project benefits included in a highway safety BCA. The safety benefits result in direct and indirect impacts. Direct safety benefits are the expected reduction in crash frequency and severity. Indirect benefits include reductions in travel time, vehicle operating costs, and emissions resulting from fewer crashes. Each section provides default values to monetize project benefits.

Key Takeaways from Chapter 4:

- Safety benefits are derived from a change in safety performance (i.e., change in the frequency and/or severity of crashes), which may result in direct and indirect benefits.
- Direct safety benefits include the reduction in crash frequency and/or severity.
- To monetize direct safety benefits for a BCA, multiply the estimated change in long-term average crashes by the average comprehensive crash cost.
- Comprehensive crash costs (or societal crash costs) are generally most appropriate for monetizing the value of crashes as they capture all impacts resulting from crashes.
- Indirect safety benefits include reductions in travel time, vehicle operating costs, and emissions resulting from fewer crashes.
- This Guide does not consider direct operational and environmental impacts such as reductions in recurring delay.
- The NHTSA report, *The Economic and Societal Impact of Motor Vehicle Crashes*, provides a method to estimate and monetize the indirect safety benefits.(11)

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5. PREPARING FOR A BCA

The BCA process begins with the development of a base condition. This serves as a basis for comparing other project alternatives. In preparing for a BCA, it is also important to establish the analysis period, consider the need to evaluate uncertainty, and select a discount rate. This chapter describes these components of preparing for a BCA. The chapter also describes potential challenges and opportunities to overcome these challenges in BCA.

Chapter 5 At-A-Glance

Chapter 5 is divided into six sections:

- Section 5.1 describes the purpose and importance of establishing the base condition.
- Section 5.2 discusses the purpose of setting an analysis period for the BCA.
- Section 5.3 defines uncertainty and describes the purpose of evaluating uncertainty in BCA.
- Section 5.4 introduces the concept of discounting and appropriate discount rates.
- Section 5.5 identifies challenges and opportunities to overcome challenges in BCA.
- Section 5.6 provides a summary of the chapter.

5.1 DEVELOPING THE PROJECT BASE CONDITION

Critical to a successful BCA is development of the project base condition. The base condition is the project alternative against which the analyst evaluates other project alternatives (i.e., does the project alternative provide net benefits compared with the base condition). This is often the existing condition (or "no-build" or "do nothing" alternative), representing the continued operation of the existing transportation facility under good management practices with minor or no capital investments.

Accurately defining the base condition is critical to the success of a BCA.

The definition of the base condition can have significant impacts on the BCA; therefore, it is important to carefully define values such as existing and future traffic volumes. Further, the estimated safety performance of the base condition is the basis for highway safety BCA and related decision-making. As such, it is imperative that analysts use a reliable method to estimate the safety performance of the base condition. The following are several factors to consider in selecting an appropriate method to estimate the safety performance of the base condition:

- Data availability (years of crash, roadway, and traffic data).
- Annual fluctuation in observed crashes.
- Changes in geometric or traffic control characteristics.
- SPF availability and reliability.
- Potential for changes in traffic volume.

In addition to the factors listed above, analysts should consider the trade-off between the reliability of the method and the resources needed to conduct the analysis.

The Highway Safety Manual provides three methods to estimate the safety performance of a base condition: observed, predicted, and expected crashes.[7]

Observed crashes are the historical crashes reported for an existing site. For example, if there were 15 reported crashes at an existing intersection over the last five years, then the observed number of crashes is 15 (or 3.0 crashes per year on average). Using the observed crash frequency assumes the observed crashes before the project represent the long-term future safety performance in the absence of projects or other changes to the site. This assumption does not account for year-to-year changes in conditions at the location of interest (e.g., changes in traffic, weather, crash reporting, road conditions, land use, vehicle fleet, and driver behavior).

Predicted crashes are based on SPFs, which are mathematical models used to predict mean crash frequency based on exposure for a given facility type. For example, if the SPF for a given facility type is represented by Figure 7, and the location of interest is 2.5 miles with 7,500 vehicles per day, then the predicted number of crashes is 1.99 per year [exp(-15.22 + 1.68*ln(7500) + ln(2.5)]. If the traffic volume is expected to change during the analysis period, consider using the average value to represent the traffic volume.

$$\frac{Crashes}{year} = \exp\left[-15.22 + 1.68 * \ln(AADT) + \ln(segment\ length)\right]$$

Figure 7. Equation. Example SPF.

Using the predicted crash frequency assumes the SPF prediction is representative of future safety performance. This method accounts for changes in traffic volume and can incorporate adjustment and calibration factors to account for changes in geometrics and general time trends; however, it requires jurisdiction-specific SPFs or SPFs calibrated to local conditions. Further, the SPF should be developed using data for similar sites at which the countermeasure of interest has not been implemented. This method does not consider historical crash data for any specific location of interest in estimating future safety performance.

Expected crashes are based on the weighted average of observed and predicted crashes using the Empirical Bayes method. The weight placed on the predicted crashes is based on the statistical reliability of the SPF as well as the magnitude of the predicted crash frequency. Using the expected crash frequency assumes the combined observed and predicted crash frequency is representative of future safety performance. This method accounts for changes in traffic volume, regression-to-the-mean, and can incorporate adjustment and calibration factors to account for changes in geometrics and general time trends. This method requires jurisdiction-specific SPFs or SPFs calibrated to local conditions. Further, the SPF should be developed using data for similar sites at which the countermeasure of interest has not been implemented. If the traffic volume is expected to change during the analysis period, consider using the average value to represent the traffic volume when using SPFs to estimate predicted crashes.

Table 17 provides an overview of the characteristics associated with the three methods for estimating the safety performance of the base condition. This table can help determine when each method is (or is not) appropriate for estimating the safety performance of the base condition. The following are additional insights to help select an appropriate method:

- Research has shown the observed crashes may overestimate the crashes for the base condition, particularly when there is a high degree of annual fluctuation in the observed crashes.[4]
- If a calibrated SPF is available, the predicted or expected crashes can help to normalize annual fluctuations in observed crashes and account for changes in traffic volume.
- The observed crashes may provide a reasonable estimate when there are several years of historical crash data and limited fluctuation in crashes from year to year.
- Expected crashes are typically more reliable than predicted crashes, assuming the observed crashes for the base condition are applicable to future conditions.
- Predicted crashes are most appropriate when the observed crashes are not a good approximation of future conditions.
- Observed crashes are not a good approximation of future conditions when there are major changes to the land use, traffic operations, or facility type. For example, if a project includes road widening from two to four lanes, then the observed crash frequency under existing conditions (i.e., two-lane facility) would not represent the future safety performance under future conditions (i.e., four-lane facility).

Refer to the Highway Safety Manual for further discussion of methods to estimate the safety performance of base conditions.[7]

Table 17. Overview of methods to estimate safety performance of base condition.

Characteristics	Observed Crashes	Predicted Crashes	Expected Crashes
Method limited by large degree of annual crash fluctuation	●	--	--
Reasonable when there are several years of historical crash data with limited fluctuation	●	--	●
Appropriate to normalize annual crash fluctuations	--	●	●
Applicable when facility type changes due to countermeasure	--	●	--
Requires calibrated SPF	--	●	●
Accounts for traffic volume changes	--	●	●

Note: -- indicates not applicable.

5.2 SETTING AN ANALYSIS PERIOD

BCA attempts to capture the comprehensive costs and benefits that result from a project over the lifecycle and within a defined analysis period (e.g., 10- or 20-year time horizon). In setting an analysis period, it is necessary to define an appropriate timeframe to allow for a meaningful analysis and a fair comparison of alternatives. FHWA recommends that the analysis period include the initial construction and at least one subsequent rehabilitation action for each alternative.[8]

Using BCA, the analyst calculates the lifecycle costs and benefits of each alternative over the same analysis period. When the service life is different among project alternatives, the analyst should standardize the service life comparisons. One method to standardize the service life comparisons is to use the least common multiple of the service lives. For example, if alternative 1 has a service life of four years and alternative 2 has a service life of eight years, then the least common multiple is an analysis period of eight years. In this case, the analyst would estimate the initial cost to implement each alternative and assume one replacement of alternative 1 at the end of the fourth year.

The analyst should standardize the analysis period to ensure a fair comparison of alternatives.

Within the analysis period, alternatives may have different maintenance or rehabilitation requirements at various times. For example, the cost components for a given project may include safety-related hardware, software, and operations and maintenance costs. For alternative 1, the hardware has an estimated 10-year service life and the software requires updating every five years. For alternative 2, the hardware has an estimated 15-year service life and the software requires updates every five years. An appropriate analysis period should account for the difference in service life for the hardware. Using the least common multiple of the service lives, a potential analysis period is 30 years. For alternative 1, this would include the initial cost and two replacements (i.e., replacement in years 10 and 20). For the second alternative, this would include the initial cost and one replacement (i.e., replacement in year 15). Both alternatives would include the initial software cost and five replacements (i.e., replacements in years 5, 10, 15, 20, and 25). In this example, the 30-year analysis period provides a fair comparison between alternatives with different hardware lifespans.

As another example, consider the cost of installing a traffic signal or constructing a roundabout at an existing two-way stop-controlled intersection. If the expected service life of the traffic signal is 10 years and the expected service life of the roundabout is 25 years, then a common multiple is a 50-year analysis period.

5.3 EVALUATING UNCERTAINTY

Transportation agencies evaluate and manage uncertainty associated with transportation investments by attempting to measure uncertainty. Analysts can measure many uncertainties by quantifying the probability of occurrence and impact of an event. Analysts identify and evaluate uncertainty by answering three questions:

- **What can happen?** Uncertainties affect the BCA results. These uncertainties include changes in initial construction estimates or future rehabilitation cost overruns, inaccurate facility service life costs, or variations in traffic volumes that differ significantly from forecasts.
- **How likely is it to happen?** Some uncertainties are more likely to occur than others. For instance, it may be that the transportation agency has an excellent understanding of project costs and unlikely to have construction cost overruns.
- **What are the consequences of it happening**? In some cases, an input variable may be subject to significant variability, but any given occurrence (within a realistic range) would not substantially affect the economic justification for the project. For instance, the price of a paving material may be subject to large swings, but the benefits of an alternative using that material may be sufficiently large to maintain the alternative as the preferred alternative even if the paving material price doubles. In other cases, there may be little likelihood that an event will occur (such as an earthquake), but its occurrence would have major consequences unless the transportation agency takes certain precautions in the project's design.

Assessing uncertainty helps analysts to answer these questions and determine if efforts to mitigate uncertainty is cost-effective. The traditional means by which analysts have evaluated uncertainty is through sensitivity and probabilistic analyses. The following sections describe methods to evaluate uncertainty.

5.3.1 Sensitivity Analysis

The traditional means by which analysts have evaluated uncertainty is through sensitivity analysis. A sensitivity analysis provides a method to alleviate concerns related to the quality or credibility of data or specific inputs. In a typical sensitivity analysis, the value of an input variable identified as a significant potential source of uncertainty is changed (either within some percentage of the initial value or over a range of reasonable values) while all other input values are held constant, and the amount of change in analysis results is noted. This sensitivity process is repeated for other input variables for which uncertainty has been identified. The input variables may then be ranked per the effect of their variability on BCA results.

In highway safety analysis, analysts can consider the certainty (or uncertainty) of the estimated change in crashes by computing a confidence interval. The analyst would have more certainty in the estimated change in crashes, and resulting benefits, as the width of the confidence interval decreases. For example, if the CMF is 0.75 with a 95 percent confidence interval of 0.41 to 1.09, then there is a 95 percent chance that the true CMF value is between 0.41 and 1.09. If the confidence interval includes 1.0, as in this example, then the countermeasure may result in a reduction, no change, or an increase in crashes. To incorporate this measure of uncertainty in highway safety BCA, the analyst could use the end points of the confidence interval (e.g., 0.41 and 1.09) in addition to the point estimate of the CMF when estimating the change in crashes and resulting benefits. Refer to FHWA's guide, Quantifying Safety in the Roadway Safety Management Process, for further discussion on estimating the confidence interval.(34)

5.3.2 Probabilistic Analysis

Continued advances in computing power permit the practice of probabilistic-based uncertainty analysis, most often through a method known as Monte Carlo simulation. In Monte Carlo simulation, the analyst assigns an appropriate probability distribution (based on expert opinion, historical data, and other information) to each of the input variables subject to uncertainty in the economic analysis. The Monte Carlo simulation draws random samples from the probability distributions for each input, runs the selected input values through the BCA formula to calculate a discrete economic result, and then repeats this process numerous times. The results, based on the randomly selected input values, produce an average BCA measure and an associated probability distribution to indicate the range of potential outcomes of the BCA. Refer to the Economic Analysis Primer for further details on probabilistic analysis and other fundamental economic analysis concepts.(8)

5.4 DISCOUNTING

The most basic economic questions that people face in their personal and business lives involve the tradeoffs between dollars earned, spent, or invested today and those dollars they hope to earn, spend, or invest in the future. Project lifecycle evaluation is important for transportation projects as these activities can be long-lived and require initial and periodic capital investments, as well as ongoing materials and maintenance expenditures.

Figure 8 shows an example distribution of project costs and benefits over time. These typically include initial construction costs (year 0), annual maintenance costs (years 1 to 4, 6 to 9, 11 to 14, and 16 to 19), and periodic rehabilitation and reconstruction costs (years 5, 10, 15, and 20). The periodic rehabilitation and reconstruction costs are necessary if the analysis period is longer than the expected service life of the project. Benefits may grow rapidly in the first few years after implementation and level out in later years as the public becomes accustomed to the project. The assumption of increasing benefits, as shown in the figure, does not necessarily apply to all projects, but depends on which strategy the agency implements. Some strategies, such as pavement markings or enhanced surface friction, may have the greatest benefits in the first few years after implementation, then lose effectiveness due to degradation over time.

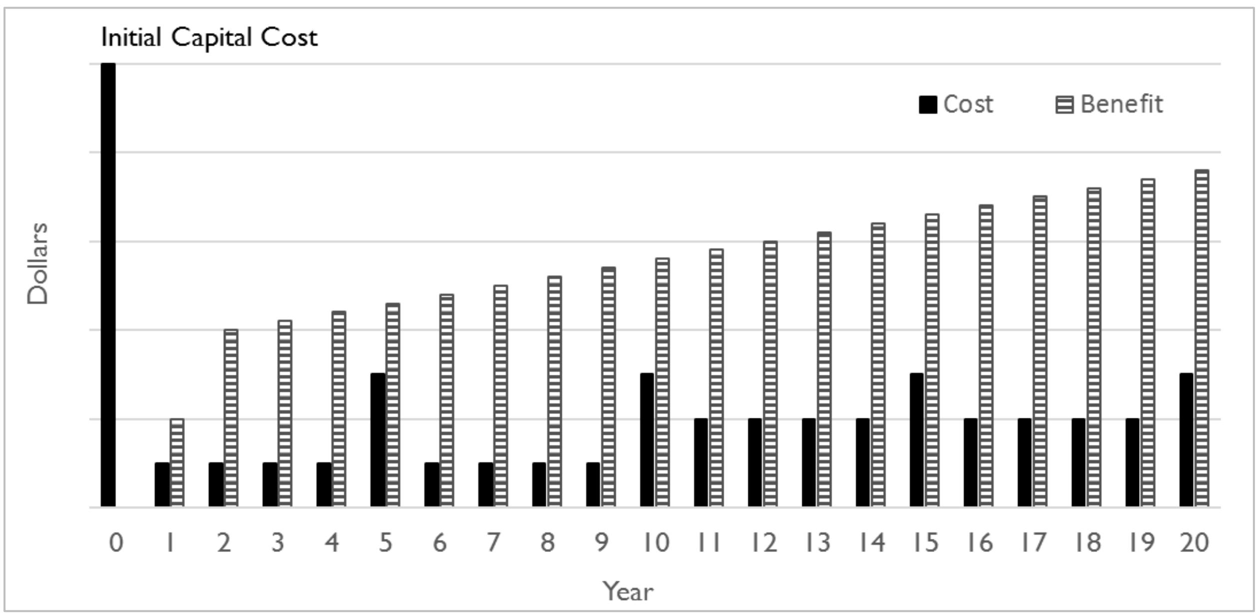

Figure 8. Chart. Time series of costs and benefits (in constant dollars).[8]

A dollar that an agency spends or earns in the future is almost always worth less to them today than a dollar they spend or earn now. The BCA quantifies the changing value of the dollar to enable meaningful comparisons of multiyear dollar streams. Two separate and distinct factors account for why the value of a dollar, as seen from the present, diminishes over time. These factors are inflation and the time value of resources, also referred to as "discounting."

Two separate and distinct factors account for why the present value of a dollar diminishes over time: inflation and discounting.

5.4.1 Inflation

In the case of economic analysis of investments by a public agency, the suggested practice is to forecast lifecycle costs and benefits of a project without inflation (i.e., in real or base year dollars). Inflation is hard to predict, particularly in the long-term for a project meant to be in service for decades. More importantly, if the BCA adds inflation to the calculation of benefits and costs projected for future years, it will only have to be removed again before these benefits and costs can be compared in the form of dollars in any given base year.

Inflation is generally not considered in BCA.

5.4.2 Discounting

The application of the discount rate to future sums to calculate their present value is known as "discounting." Through discounting, the BCA can objectively compare different investment alternatives based on their respective present values, even though each has a different stream of future benefits and costs.

Figure 9 and Figure 10 provide the formulas for discounting. For example, if the discount rate is 3.0 percent, the discount factor (from Figure 10) for 10 years in the future is 0.744 (1/(1.03^10)). If the estimated benefit is $1000 for 10 years in the future, then the present value (from Figure 9) is $744 (0.744 * $1000).

$$PV = \left(\frac{1}{(1+r)^t}\right) A_t$$

Figure 9. Equation. Standard formula for discounting.

where:

PV = present value at time zero (the base year).

r = discount rate.

t = time (year).

A_t = amount of benefit or cost in year t.

$$\frac{1}{(1+r)^t}$$

Figure 10. Equation. Discount factor.

Most transportation projects generate costs and benefits over their entire lifecycle. The BCA should discount the entire series of costs and benefits to the present by multiple applications of the PV formula for each applicable year of the lifecycle. Figure 11 provides the formula for this calculation. These discounted values are then summed together (as represented by ∑) for each year of the lifecycle analysis period (N years) to yield an overall present value.

$$PV = \sum_{t=1}^{N} \left(\frac{1}{(1+r)^t}\right) A_t$$

Figure 11. Equation. Summation of discounted values.

5.4.3 Selecting a Discount Rate

Economic analysis should include real terms (i.e., using dollars and discount rates that do not include the effects of inflation). The BCA can estimate the real discount rate by removing the rate of inflation as measured by a general price index such as the CPI from a market or nominal interest rate for government borrowing. The CPI is developed and maintained by the US Department of Labor, Bureau of Labor Statistics. The CPI represents changes in prices of all goods and services purchased for consumption by urban households. User fees (such as water and sewer service) and sales and excise taxes paid by the consumer are also included. Income taxes and investment items (like stocks, bonds, and life insurance) are not included. The selected market rate for government borrowing should be based on government bonds with maturities comparable in length to the analysis period used for the economic analysis. Real discount rates calculated in this manner have historically ranged from just below zero percent to five percent, which are the rates most often used by States for discounting highway investments.

The 2017 Benefit-Cost Analysis Guidance for TIGER and INFRA Applications notes that applicants should discount future benefits and costs to present values using a real discount rate (i.e., a discount rate that reflects the opportunity cost of money net of the rate of inflation) of seven percent, following guidance provided by the OMB in Circular A-94. Grant applicants may also provide an alternative analysis using a real discount rate of three percent, for example. In conducting BCA, the analyst should review the current OMB or State guidance on the appropriate discount rate to use at the time of the analysis as this value will change over time and location. OMB provides an annual memorandum providing appropriate discount rates. The 2017 rate for long-lived projects (meaning 10 years or more) is seven percent. Agencies may perform a sensitivity analysis to determine how the discount rate impacts the results and use a lower discount rate (e.g., three percent) if it better suits their needs.

Typical discount rates range from 3 to 7 percent.

5.5 CHALLENGES AND OPPORTUNITIES

A BCA is a powerful, informative tool available to assist planners, engineers, and decision makers. Nevertheless, public agencies may avoid or underutilize BCA due to misconceptions. In some cases, agency personnel are skeptical about the accuracy of a BCA due to perceived uncertainties in measuring or valuing costs and benefits. The analyst can often measure and manage uncertainty where it exists, as described in section 5.3, *Evaluating Uncertainty*. It is helpful to remember that sound economic analysis reduces uncertainty. Not performing the analysis only serves to hide uncertainty from decision makers.

The following are opportunities related to BCA:

- Determine the cost-effectiveness of lifecycle costs, user benefits, and externalities.
- Provide documentation of decision-making and assumptions used in the analysis.
- Compare the economic effects of project alternatives.
- Make proactive decisions.
- Identify economically-efficient investments.
- Determine if a project or program should be undertaken and when.
- Determine which alternative and programs should be funded.

While there are several benefits related to BCA, transportation professionals should be aware of challenges and limitations associated with BCA. Table 19 presents potential challenges and opportunities to overcome those challenges in highway safety BCA.

Table 18. Frequently asked questions and answers for applying crash costs.

CHALLENGE	OPPORTUNITY
Data quality: A BCA can be data intensive, and its accuracy and precision depend on the quality of the input data.	Analysts should take extra care in reviewing input data to assure accuracy, and test the importance of assumptions by running alternate scenarios and performing sensitivity analysis.
Limited data capabilities: There may be a lack of data capabilities to estimate the long-term safety performance of alternatives.	Efforts are underway to improve safety data capabilities such as the availability of crash and traffic volume data needed to estimate predicted and expected crashes. Efforts are also underway in many States to develop or calibrate SPFs.
Quantifying air emissions and noise impacts: It may be difficult to estimate air emissions and noise impacts as these estimates can	The EIS or EA generally quantifies the project's impact to air quality, noise levels, and natural environment. Analysts can use NEPA studies to quantify the impact of externalities for use in a BCA. Analysts could also

Challenge	Opportunity
require field measurement and specialized expertise.	use environmental impacts described in NEPA studies to qualitatively evaluate and compare alternatives.
Uncertainty in assumed values: When transportation professionals collect data to support a BCA, there may be uncertainty in assigning engineering and economic values to inputs and the resulting outputs. The level of confidence in the analytical results depends on the relative certainty of the analysis methods and underlying data.	Sensitivity analysis is an important part of economic evaluation. Modern analysis tools give users the ability to test several assumptions with little effort through sensitivity analysis where key assumptions are modified.
Ambiguous or inaccurate base condition: If the analyst improperly defines the base condition, then the resulting comparison of alternatives may be misleading.	The analyst can better define the base condition with more detailed and reliable data. It is important to define the base condition to represent the conditions expected in the future if the project is not implemented. Benefits accrue from the difference expected from the implementation of a project compared to the future conditions without the project.
Accuracy in estimating benefits: It is not always clear whether prior research from other locations or contexts is transferable to a new project.	Benefit transfer is an economic analysis technique utilized when local data are not available. As data become available, the analyst can refine the inputs and improve the accuracy of the results.
Transparency and reproducibility: Analysis techniques may lack transparency and reproducibility in procedures and results.	Modern analysis tools assist the analyst in producing BCA results that are transparent, testable, and reproducible.
Regulatory requirements: The investment of Federal and some State funds require agencies to conduct a BCA prior to the allocation of those funds. There may be State regulatory requirements or policies that force transportation professionals to consider specific criteria, costs, or benefits.	While the regulatory requirements may add to the burden of the project development process, the BCA results add value to the decision-making process.

CHALLENGE	OPPORTUNITY
Lack of expertise and support: There may be a lack of technical expertise or institutional support within transportation agencies to conduct BCA or to perform a rigorous analysis.	Great strides have been made by transportation agencies to understand and utilize BCA in decision making. USDOT requires BCA in most grant programs as a condition of funding and makes resources like this Guide and Tool available to agencies.
Concerns that the results of BCA could conflict with preferred or mandated outcomes: Engineers, transportation professionals, or the agency may have a preferred alternative prior to economic analysis, which they may not want to stray from regardless of the economic benefits or impacts.	An objective and independent assessment of the economic consequences of a project can contribute valuable information to the decision process. There may be an opportunity for the agency to establish requirements or policies that force transportation professionals to perform a BCA.

There are valid reasons why decision makers may choose to override or constrain economic information. For example, if there are concerns that BCA results would disproportionately favor projects in urban areas, policy makers can initially allocate funds between urban and rural areas based on equity considerations. In this example, urban projects would then compete based on their economic merits for the urban funds; rural projects would similarly compete for the rural funds.

Another common hurdle involves the evaluation of a project that is a combination of two or more independent, separable countermeasures. In such cases, the benefits of one may hide the costs of the other. If building both maximizes their synergy, then considering each individually may produce unfavorable results and lead to building neither.

As with any analysis method, BCA can, if misused, give erroneous results. Perhaps the first cause of error in a BCA is the selection of an unrealistic base condition. Further, the comparison of only one alternative to the base condition when other, potentially less costly, alternatives exist, may bias the results. Poor data and analytical assumptions can also lead to erroneous results, but this is handled by improving data collection methods, and carefully documenting the process for calculating project costs and benefits.

Related to data inputs, it is important to include complete and properly-represented costs and benefits in the analysis. First, the BCA should include all relevant user and non-user costs. The analyst may overestimate benefits if they do not include the complete costs (or disbenefits) associated with a project. This occurs most often when the analyst omits user costs or major non-user costs. In some cases, an agency may focus only on local costs and benefits, failing to include those that accrue outside its immediate jurisdiction. Second, the analyst should take care not to include benefits that are simply restatements of other benefits (or costs) measured elsewhere in the BCA. This latter error, a form of double counting, can occur when the analyst measures employment, business, or land use effects using an economic impact analysis, and then adds the benefits of travel-time savings, safety improvements, and vehicle operating cost reductions. For example, land uses and values can change due to transportation investments. The land use changes stem, in part, from the reduced travel time. Counting both travel time savings and land use impacts would be double counting. The differences between efficiency improvements and impacts distinguish BCA from economic impact analysis.

It is important to include complete and properly-represented costs and benefits in a BCA.

5.6 CHAPTER SUMMARY

Chapter 5 describes the key components and considerations in preparing for a BCA. It describes the process for developing the base condition, setting an analysis period, evaluating uncertainty in a BCA, and selecting an appropriate discount rate. It concludes with a discussion of challenges encountered during BCA and opportunities to overcome those challenges.

Key Takeaways from Chapter 5:

- Accurately defining the base condition is critical to the success of BCA.
- The analyst should standardize the analysis period to ensure a fair comparison of alternatives.
- One option for standardizing the analysis period is to use the least common multiple of the service lives.
- Uncertainty is evaluated through sensitivity and probabilistic analysis.
- Two separate and distinct factors account for why the present value of a dollar diminishes over time: inflation and discounting.
- Inflation is generally not considered in BCA.
- A BCA measures the time value of resources by an annual percentage factor known as the discount rate. Typical discount rates range from three percent to seven percent, which can change over time. Some grant programs specify the required discount rate while each agency may establish its own discount rate for internal BCA.
- While there are several potential challenges to performing a BCA (e.g., data and analysis capabilities, uncertainty in analysis parameters, and regulatory requirements), there are at least as many opportunities to overcome those issues.

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6. CONDUCTING BCA FOR SAFETY

The BCA process is repeatable and defensible, given the use of quality data and reliable methods to estimate project costs and benefits. This chapter describes methods to estimate safety benefits (i.e., change in crash frequency by severity level) and the derivative operational and environmental benefits (i.e., resulting impacts on travel time, travel time reliability, vehicle operating costs, and emissions). Examples illustrate the methods to estimate the safety benefits of single and multiple countermeasures at a given location. Refer to chapter 4 for default values to quantify and monetize project benefits. Refer to chapter 7 for additional examples of BCA for safety, including projects with a single countermeasure at a single location, projects with multiple countermeasures at a single location, and projects with multiple locations.

Quality data and reliable methods are key to an accurate BCA and defensible results.

Chapter 6 At-A-Glance

Chapter 6 is divided into six sections:

- Section 6.1 presents a method to estimate the change in safety performance.
- Section 6.2 presents a method to estimate the change in travel time related to safety.
- Section 6.3 presents a method to estimate the change in travel time reliability related to safety.
- Section 6.4 presents a method to estimate the change in fuel use related to safety.
- Section 6.5 presents a method to estimate the change in emissions related to safety.
- Section 6.6 provides a summary of the chapter.

6.1 ESTIMATING SAFETY BENEFITS

Safety benefits are the expected change in crash frequency associated with a project alternative relative to the base condition. In general, there is a need to estimate the safety performance of the base condition, then estimate the safety performance of the alternative condition, and finally take the difference to estimate the expected change in safety. One option for estimating the change in safety is to apply CMFs to the long-term average safety performance for the base condition. When relevant CMFs are not available, it may be appropriate to estimate the change in safety performance by comparing the predicted crashes from one or more SPFs. For example, CMFs do not exist for a project that would convert a rural, two-lane, undivided highway to a rural, multilane, undivided highway; however, the Highway Safety Manual Part C

Predictive Method provides SPFs and corresponding adjustment factors to estimate the safety performance of these two conditions.(7)

This Guide focuses on the use of CMFs to estimate the change in safety performance, assuming the analyst has estimated the average annual crashes for the base condition. Refer to section 5.1 for developing the base condition. Refer to the Highway Safety Manual Part C Predictive Method for further details on how to use SPFs and adjustment factors to estimate the safety performance of the base condition and alternatives.(7) The Interactive Highway Safety Design Model (IHSDM) and Highway Safety Manual spreadsheets are available to support the use of the Highway Safety Manual Part C Predictive Method. State-specific SPFs may also be available for such applications in estimating safety performance.

When possible, it is preferred to estimate the change in crashes by crash severity or crash type. This allows for a more comprehensive analysis, considering the potential for different changes by crash category. For example, if an agency is considering the installation of a cable median barrier, this will likely reduce fatal and injury crashes, but may increase PDO crashes. This can have an impact on the economic analysis because the average crash cost differs by crash severity and crash type. When estimating the change in crashes by severity, the analyst can apply crash costs by severity to reflect the difference in cost by severity. The analyst can then aggregate the crash costs among the severity levels to estimate the net monetary benefit.

This Guide estimates the change in crashes by severity for reasons discussed in Table 8. Further, the methods described in the following sections for estimating reductions in travel time, vehicle operating costs, and emissions are based on changes in crash frequency by severity level. This Guide uses the KABCO scale for injury severity as defined in section 4.1. To convert combined severity levels (e.g., combined fatal and injury crashes) to the KABCO scale, it is necessary to develop and apply a local crash severity distribution. Refer to section 6.1.2 below for an example of how to convert combined severity levels to the KABCO scale. Refer to the Highway Safety Manual for further information and additional guidance on developing estimates of annual crashes by severity and developing local severity distributions.(7)

This section describes two primary scenarios for applying CMFs: 1) estimating the safety effect of a single countermeasure, and 2) estimating the safety effect of multiple countermeasures. It then explains the process of applying average crash costs to estimate the monetary benefits related to the expected change in crashes. Examples are provided to illustrate the application of CMFs and crash costs. It concludes with a discussion of how to apply CMFs to estimate the safety benefits associated with projects applied at multiple locations (e.g., systemic countermeasures). This Guide assumes readers are familiar with the selection of applicable CMFs. Refer to the CMF Clearinghouse for further guidance and resources on selecting and applying CMFs to estimate safety benefits.

CMFs are key to estimating the expected change in crash frequency.

6.1.1 Estimating the Safety Benefit of a Single Countermeasure

Figure 12 shows the equation for estimating the crash frequency for the condition with the treatment of interest. This is estimated as the crash frequency for the base condition multiplied by the corresponding CMF, where the CMF represents the expected safety effect of the treatment relative to the base condition. The safety benefit (or disbenefit) is the difference in the estimated long-term crash frequency with and without treatment.

$$Estimated\ Crashes\ with\ Treatment = Estimated\ Crashes\ for\ Base\ Condition * CMF$$

Figure 12. Equation. Estimating crashes for a single countermeasure.

This is a simple CMF application, using a CMF for total crashes to estimate the change in total crashes. It is often more reliable to estimate the expected change in crashes by severity when possible. This requires applicable CMFs by severity and estimates of crashes by severity for the base condition. Further, it is important to apply crash costs by severity to the estimated change in crashes by severity before aggregating to a net monetary benefit. The following example illustrates the application of CMFs to estimate the change in crashes by severity.

It is often more reliable to estimate the expected change in crashes by severity.

6.1.2 Example of Estimating the Safety Benefit of a Single Countermeasure

An agency is considering the installation of a cable median barrier and would like to estimate the expected change in crashes by severity. The analyst identifies applicable CMFs from the CMF Clearinghouse. The applicable CMF for fatal crashes is 0.57 (CMF ID 42), the applicable CMF for injury crashes is 0.70 (CMF ID 43), and the applicable CMF for PDO crashes is 1.60 (note this CMF is an estimate based on local crash severity distributions and CMF IDs 42, 43, and 44). This example assumes the CMF for injury crashes (i.e., all A-, B-, and C-level crashes combined) applies to each individual injury severity. Table 19 shows the long-term average crashes per year by severity under base conditions for the hypothetical scenario, the CMFs for the respective crash severity levels, the estimated crash frequency with treatment, and the expected change in crashes by severity. For example, the estimated annual K-level crashes under base conditions is 0.1 crashes per year and the applicable CMF is 0.57. Applying the equation in Figure 12 results in an estimate of 0.057 K-level crashes per year with treatment (0.57 * 0.1). The difference is an estimated change (in this case a reduction) of 0.043 K-level crashes per year.

Table 19. Example application of CMFs by severity.

Crash Severity	Estimated Annual Crashes for Base Conditions	Applicable CMF	Estimated Annual Crashes With Treatment	Estimated Annual Reduction in Crashes
K	0.1	0.57	0.057	0.043
A	1.2	0.70	0.84	0.36
B	2.4	0.70	1.68	0.72
C	4.0	0.70	2.80	1.20
O	10.0	1.60	16.00	-6.00
Total	17.7	--	21.377	-3.677

Note: -- indicates not applicable.

The net benefit is the sum of the estimated change in crashes by severity. In this case, the net impact is an increase of 3.677 crashes per year (17.7 crashes under base conditions – 21.377 crashes with treatment). At first glance, it may appear that this alternative will not provide a safety benefit; however, there is a reduction of 2.323 fatal and injury crashes. To estimate the net monetary benefit, it is important to apply crash costs by severity to the estimated change in crashes by severity before aggregating benefits across severity levels.

Table 20 shows the estimated annual change in crashes from Table 19 and the average crash costs by severity from Table 9. The estimated annual monetary benefit is the product of the estimated annual change in crashes and the average crash cost for the respective severity level. For example, the estimated annual change in A-level crashes is 0.36 crashes per year and the average cost of an A-level crash is $674,400. The result is a safety benefit of $242,784 per year (0.36 A-level crashes per year * $674,400 per A-level crash). Aggregating the annual monetary benefits across severity levels indicates the net monetary benefit. Now, it is apparent that the installation of a median barrier is expected to provide a net safety benefit of $972,366 per year.

Table 20. Example application of crash costs by severity.

Crash Severity	Estimated Annual Reduction in Crashes	Average Crash Cost by Severity	Estimated Annual Monetary Benefit
K	0.043	$11,637,900	$500,430
A	0.36	$674,400	$242,784
B	0.72	$204,100	$146,952
C	1.20	$129,000	$154,800
O	-6.00	$12,100	-$72,600
Total	-3.677	--	$972,366

Note: -- indicates not applicable.

While the application of CMFs and crash costs by severity is the preferred approach to estimate net safety benefits, the approach is dependent on the availability of quality CMFs and the ability to estimate the annual crashes for base conditions by crash severity. In some cases, CMFs may only be available for total crashes or combinations of injury crashes (e.g., all KABC crashes combined). As shown in the previous example, the CMF often varies by crash severity. Until further research is completed to develop CMFs by individual severity level, one option is to assume the CMF is the same for all crash severity levels included in the original CMF. For example, if the original CMF is 0.8 and applies to total crashes, then the analyst could assume the CMF is 0.8 for K, A, B, C, and O crashes. If two CMFs are available, one for KABC crashes (i.e., all injury crashes combined) and one for PDO crashes, the analyst could assume the CMF for KABC crashes is representative of K, A, B, and C crashes individually and the CMF for PDO crashes represents O crashes individually. Again, it is important to recognize the limitations of this assumption, which may lead to over- or underestimating changes in specific severity levels.

The preferred approach to estimate net safety benefits is to apply CMFs and crash costs by severity.

When the estimated annual crashes for base conditions represent combined severity levels, it is necessary to apply local crash severity distributions to develop estimates for the individual categories of K, A, B, C, and O crashes. For example, consider a scenario in which the analyst has an estimate of total annual crashes (i.e., all severity levels combined). The analyst would like to develop individual estimates of annual K, A, B, C, and O crashes. To do so, there is a need to develop and/or apply the local distribution of K, A, B, C, and O crashes. For example, if the contemplated project is along a rural, two-lane road, then the analyst could develop the local severity distribution by tabulating all crashes by severity level on rural, two-lane roads.

Analysts can use local crash severity distributions to develop estimates for individual crash severity levels (K, A, B, C, and O).

Table 21 shows an example for which the total crashes are tallied by severity. Of the 100 crashes along rural, two-lane roads in this jurisdiction, there are 2 K-level crashes, 5 A-level crashes, 11 B-level crashes, 15 C-level crashes, and 67 PDO crashes. To estimate the individual annual crashes by severity level, the analyst would apply the proportions in Table 21 to the estimate of total annual crashes (i.e., all severity levels combined) at the specific location.

Table 21. Example of local severity distribution for total crashes.

Crash Severity	Crash Count by Severity Level	Proportion of Crashes by Severity Level
K	2	0.02
A	5	0.05
B	11	0.11
C	15	0.15
O	67	0.67
Total Crashes	100	1.00

As another example, consider a scenario in which the analyst has estimates of annual KABC crashes (i.e., all injury crashes combined) as well as annual PDO crashes. The analyst already has an individual estimate for PDO crashes, but there is a need to develop individual estimates of annual K, A, B, and C crashes. In this case, the analyst would need to develop and apply the severity distribution of K, A, B, and C crashes, as the proportion of all injury crashes. Using the data presented in Table 21, the sum of all injury crashes is 33 (2 + 5 + 11 + 15). The proportion of K, A, B, and C crashes, relative to all injury crashes, are 0.06, 0.15, 0.33, and 0.45, respectively. To estimate the individual annual K, A, B, and C crashes, the analyst would apply these proportions to the estimate of annual KABC crashes (i.e., all severity levels combined).

Refer to the Highway Safety Manual for further information and additional guidance on developing estimates of annual crashes by severity and developing local severity distributions.[7]

6.1.3 Estimating the Safety Benefit of Multiple Countermeasures

An agency may apply multiple countermeasures at a single location, such as signalizing a stop-controlled intersection, adding turn lanes, and reducing the intersection skew. Each of these countermeasures may have an associated CMF or a single CMF may represent the combined effect of the countermeasures. The preferred approach to estimating the combined effect of multiple countermeasures is to use a single CMF that represents the combined effect of the countermeasures. If a single CMF is available, the analyst would follow the process described in section 6.1.1, *Estimating the Safety Benefit of a Single Countermeasure*, to estimate the safety benefit. In the absence of such a CMF, the analyst may need to apply one or more CMFs to estimate the combined safety effect.

The preferred approach to estimating the combined effect of multiple countermeasures is to use a single CMF that represents the combined effect.

In the absence of a CMF for the combined effect of multiple countermeasures, a single method for estimating the combined effect is not appropriate in all scenarios. One consideration is the applicability of the CMFs, as it is not appropriate to multiply two or more CMFs that apply to different crash types and/or severities. Another consideration is the potential overlap among individual countermeasures. Specifically, the effects of two or more countermeasures may complement, overlap, or counteract each other. The analyst should apply judgment to determine the likelihood and extent of overlapping effects among the contemplated countermeasures, and select an appropriate method to estimate the combined safety benefit.

In general, the following guidance applies when the CMFs for two countermeasures apply to the same crash types and severities:

- When there is complete overlap in countermeasure effects, the Dominant Effect method generally performs well. The Dominant Effect method applies only the CMF for the most effective countermeasure. In most cases, the Dominant Effect method provides a conservative estimate of benefits and is appropriate for estimating the combined safety effect of multiple countermeasures within a single project. The Dominant Effect method may produce inconsistent estimates of the combined effect for different combinations of countermeasures. As such, the analyst should be cautious in comparing the results from the Dominant Effect method among projects.
- When multiple countermeasures are truly independent (i.e., zero overlap in crashes impacted by the countermeasures), it is appropriate to assume the full effect of both countermeasures using the Additive method. Figure 13 shows the equation for the Additive method, which has an upper bound of 100 percent for the maximum effect of multiple countermeasures ($CMF_t \geq 0$).

$$\mathrm{CMF_t} = 1 - [(1 - \mathrm{CMF_1}) + (1 - \mathrm{CMF_2})]$$

Figure 13. Equation. Additive method for estimating the combined benefit of multiple countermeasures.

where:

CMF_t = CMF for the combined countermeasures.

CMF_1 = CMF for the most effective countermeasure.

CMF_2 = CMF for the second most effective countermeasure.

- When both CMFs are less than 1.0, and there is some overlap in countermeasure effects (i.e., second most effective countermeasure provides additional benefit, but the full effect of the second most effective countermeasure is not realized due to overlap with the most effective countermeasure), the Dominant Common Residuals method generally performs well. Figure 14 shows the equation for the Dominant Common Residuals method. In some cases, this method will produce a combined CMF that is greater than the CMF for the most effective countermeasure. For example, if CMF_1 is 0.40 and CMF_2 is 0.80, then the combined effect (CMF_t) using the equation in Figure 14 is 0.63. In cases where the Dominant Common Residuals method produces a combined CMF that is greater than the CMF for the most effective countermeasure, the Dominant Effect method is more appropriate, assuming the combination of countermeasures is as effective as the most effective countermeasure.

$$\mathrm{CMF_t} = (\mathrm{CMF_1} * \mathrm{CMF_2})^{CMF_1}$$

Figure 14. Equation. Dominant common residuals method for estimating the combined benefit of multiple countermeasures.

where: all terms as defined previously.

- When both CMFs are greater than 1.0 or there is a counteractive effect (i.e., second countermeasure counteracts the effect of the first countermeasure), the Multiplicative method generally performs well. Figure 15 shows the equation for the Multiplicative method. This is a common scenario in the evaluation of design exceptions. For example, a highway designer may consider installing advance curve warning signs to offset the potential safety impacts of reducing the radius of curve due to topographical constraints.

$$\mathrm{CMF_t} = \mathrm{CMF_1} * \mathrm{CMF_2}$$

Figure 15. Equation. Multiplicative method for estimating the combined benefit of multiple countermeasures.

where: all terms as defined previously.

The prior guidance applies when the CMFs for two countermeasures apply to the same crash types and severities. When the CMFs for two countermeasures apply to different crash types and/or severities, it is necessary to apply the CMFs individually to the respective crashes under base conditions, and then aggregate, rather than combine the CMFs. The following four-step process is generally applicable for estimating the combined effect of multiple countermeasures when the individual CMFs apply to different crash types and/or severities:

1. Apply the CMF for the most effective countermeasure to the estimated crashes for the applicable crash type/severity under base conditions.
2. Apply the CMF for the second most effective countermeasure to the estimated crashes for the applicable crash type/severity under base conditions.
3. Sum the estimated change in crashes to calculate the net effect.
4. Check that the estimated change does not exceed 100 percent.

Using this four-step process, the analyst can apply the following guidance based on the potential for overlapping countermeasure effects:

- When there is complete overlap in countermeasure effects, the Dominant Effect method is appropriate. The Dominant Effect method applies only the CMF for the most effective countermeasure. In this case, only step 1 is applicable, eliminating the need for steps 2 – 4.
- When multiple countermeasures are truly independent (i.e., zero overlap in crashes impacted by the countermeasures), it is appropriate to assume the full effect of both countermeasures with an upper bound of 100 percent reduction ($CMF_t \geq 0$). In this case, all four steps are applicable.
- When there is some overlap in countermeasure effects, it is appropriate to expect the full benefit of the most effective countermeasure and some additional benefit from the second countermeasure. In this case, prior to performing step 2, consider removing any crashes from the base condition that are already included in the base condition in step 1. Specifically, apply the CMF for the second countermeasure to only those base condition crashes that are not already included in step 1.

Some methods perform better than this abbreviated guidance in specific scenarios. As such, a more reliable approach for estimating the benefits of multiple countermeasures is to follow the method selection process described in NCHRP Report 17-63, *Guidance for the Development and Application of Crash Modification Factors*.(35)

6.1.4 Example of Estimating the Safety Benefit of Multiple Countermeasures

An agency is considering the implementation of two countermeasures at an intersection along a rural principal arterial and would like to estimate the expected change in crashes by severity. The analyst identifies applicable CMFs from the CMF Clearinghouse and determines the CMFs apply to the same crash type and severity levels. Further, the analyst determines there is likely some overlap in the countermeasure effects. For the first countermeasure, the applicable CMF for fatal and injury crashes is 0.75 and the applicable CMF for PDO crashes is 1.10. For the second countermeasure, the applicable CMF for fatal and injury crashes is 0.80 and the applicable CMF for PDO crashes is 0.85. While it is preferred to use CMFs for the individual categories of K, A, B, C, and O, CMFs do not always exist at this level of detail. In the absence of such CMFs, one option is to assume the CMFs for fatal and injury crashes (i.e., all KABC crashes combined) apply to each individual injury severity as described in section 6.1.2, *Example of Estimating the Safety Benefit of a Single Countermeasure*.

Table 22 shows the CMFs by crash severity for both individual countermeasures, the selected method for estimating the combined effect, and the estimated combined CMFs. The analyst selects the Dominant Common Residuals method to estimate the combined effect on fatal and injury crashes because both CMFs are less than 1.0 and there is some overlap expected in the countermeasure effects. The analyst selects the Multiplicative method to estimate the combined effect on PDO crashes because there is a counteractive effect (i.e., $CMF_1 > 1.0$ and $CMF_2 < 1.0$).

Table 22. Example of combining CMFs.

Crash Severity	Applicable CMF for Countermeasure 1	Applicable CMF for Countermeasure 2	Method to Estimate Combined Effect	Estimated Combined CMF
K	0.75	0.80	DCR	0.68
A	0.75	0.80	DCR	0.68
B	0.75	0.80	DCR	0.68
C	0.75	0.80	DCR	0.68
O	1.10	0.85	Multiplicative	0.94

Note: DCR = Dominant Common Residuals.

Table 23 shows the long-term average crashes per year by severity under base conditions for the hypothetical intersection, the estimated combined CMF by severity from Table 22, the estimated crash frequency with treatment, and the expected change in crashes by severity. For example, the estimated annual K-level crashes under base conditions is 0.1 crashes per year and the combined CMF is 0.68. Applying the equation in Figure 12 results in an estimate of 0.068 K-level crashes per year with treatment (0.68 * 0.1). The difference is an estimated change (in this case a reduction) of 0.032 K-level crashes per year.

Table 23. Example application of CMFs for multiple countermeasures.

Crash Severity	Estimated Annual Crashes for Base Conditions	Estimated Combined CMF	Estimated Annual Crashes With Treatment	Estimated Annual Reduction in Crashes
K	0.1	0.68	0.068	0.032
A	1.2	0.68	0.816	0.384
B	2.4	0.68	1.632	0.768
C	4.0	0.68	2.72	1.28
O	10.0	0.94	9.4	0.6
Total	17.7	--	14.636	3.064

Note: -- indicates not applicable.

The net benefit is the sum of the estimated change in crashes by severity. In this case, the net benefit is a reduction of 3.064 crashes per year (17.7 crashes under base conditions – 14.636 crashes with treatment). To estimate the net monetary benefits, it is important to apply crash costs by severity to the estimated change in crashes by severity before aggregating to a net monetary benefit.

6.2 ESTIMATING TRAVEL TIME BENEFITS

The NHTSA report, *The Economic and Societal Impact of Motor Vehicle Crashes*, provides a methodology to estimate the average hours of delay per crash for five roadway facility types.[(11)] The NHTSA approach is particularly useful for monetizing the average delay hours per crash by severity and roadway facility type. Table 24 provides the NHTSA values to estimate total vehicle delay hours per crash by severity and roadway facility type. Refer to Table 10 for values to monetize travel time or changes in travel time.

The estimated travel time benefit (delay reduction) is the product of the estimated reduction in crashes and the vehicle delay factor (average delay per crash). Vehicle delay factors are based on the total number of vehicles delayed, assuming one person per vehicle. Vehicle delay factors represent the total person-hours of delay, not the average delay hours per person. As shown in Table 24, vehicle delay factors vary based on the crash severity and facility type, ranging from approximately ten hours per PDO crash to thousands of hours per fatal crash.

Table 24. Vehicle delay hours by crash severity and roadway type (per crash).[11]

Crash Severity	Urban Interstates/ Expressways	Urban Arterials	Urban Other	Rural Interstate/ Principal Arterials	Rural Other
Fatal	5,147.70	1,258.26	207.88	1,780.31	104.82
Injury	345.29	68.56	15.40	207.68	13.86
PDO	215.00	49.94	10.32	146.25	10.33

Table 25 provides an example calculation for monetizing the travel time benefit that results from a change in crashes. This example uses the estimated annual change in crashes from the example in Table 23, the value of time from Table 10, and the delay hours per crash from Table 24, assuming the roadway facility is classified as a rural principal arterial. For example, for A-injury crashes, the estimated delay reduction is 0.38 crashes per year * 207.68 hours per crash (from Table 24) = 79.75 hours per year.

Table 25. Example monetization of travel time for a project on a rural principal arterial (NHTSA methodology).

Crash Severity	Estimated Annual Reduction in Crashes (Table 23)	Vehicle Delay per Crash (Hours)	Delay Reduction (Hours)
K-Fatal	0.032	1780.31	56.97
A-Injury	0.38	207.68	79.75
B-Injury	0.77	207.68	159.50
C-Injury	1.28	207.68	265.83
O-PDO	0.60	146.25	87.75
Total Annual Delay Reduction (Hours)	--	--	**649.80**
Unit Value of Time per person-hour (Table 10)	--	--	**$29.18**
Total Annual Benefit	--	--	**$18,961**

Note: -- indicates not applicable.

6.3 ESTIMATING TRAVEL TIME RELIABILITY BENEFITS

The SHRP2 C-11 Reliability Module provides a spreadsheet tool to assess travel time reliability. The procedure is based on making estimates of recurring and nonrecurring congestion, combining these estimates, and using predictive equations to develop reliability metrics. This Guide and the Tool apply the SHRP2 C-11 procedures for estimating the time saved by more reliable trips. These calculations are carried out using default values, user supplied inputs, and internal calculations to estimate the change in buffer time.

The buffer time savings estimate involves minimal data development and model calibration, which simplifies the analysis process, particularly for analysts who are not experts in traffic engineering. To complete the estimation, the following data are required for the road segments of interest:

- Roadway facility type (i.e., urban interstate/expressway, urban arterial, urban other, rural interstate/principal arterial, or rural other).
- Analysis period (years).
- Length of construction period (years).
- Segment length (miles).
- Number of lanes (2 for two-lane roads; otherwise, number of lanes per direction).
- Free flow speed (mph).
- Traffic volume during peak period (total vehicles for all lanes = number of vehicles/hour/lane * number of lanes * number of hours in peak period).
- Link capacity during peak period (passenger car equivalents for all lanes, or estimated by the Highway Capacity Manual methods).
- Hours of peak traffic per day (e.g., number of hours in am and/or pm peak).
- Days of analysis per year (e.g., 365 for analysis of all days or 260 for analysis of weekday travel time reliability).
- Annual discount rate (percent).
- Percent of trucks in the flow (percent).
- Personal value of time ($ per hour).
- Freight value of time ($ per hour).
- Reliability ratio personal (unitless).
- Reliability ratio freight (unitless).
- Percent reduction in crash frequency for each alternative (based on CMFs).

The NHTSA approach defines safety-related benefits for five roadway facility types.[11] The SHRP2 methods use five slightly different facility types from the Highway Capacity Manual (HCM) to estimate capacity and the related reliability benefits. In general, these align with the Highway Performance Monitoring System (HPMS) functional classification categories, where the urban and rural 'other' categories include major and minor collector and local roads. The user should select one of the NHTSA roadway facility types as being most representative of the HCM facility of interest. The HCM categories are linked to the NHTSA categories as follows:

- HCM Urban Freeway = NHTSA Urban Interstate/Expressway.
- HCM Principal Arterial = NHTSA Urban Arterial.
- HCM Urban Other = NHTSA Urban Other.
- HCM Rural Freeway = NHTSA Rural Interstate/Principal Arterial.
- HCM Rural Other = NHTSA Rural Other.

Reliability is a concept related to trip time planning. A less reliable trip requires additional travel time, referred to as buffer time, to assure an acceptable level of on-time arrival certainty. Thus, the user should define a segment over which to estimate the change in buffer time from a project. Segments can be of any length, but it is recommended that they not be so long that the characteristics change dramatically along the segment, or too short that input is burdensome. The following are examples of reasonable segment lengths:

- Restricted access roadways (e.g., freeways and interstates): define the analysis section between two or more interchanges.
- Signalized arterial corridors: define the analysis section between two or more signals.
- Rural highways (non-freeways): define the analysis section in 2- to 5-mile segments.

The companion Highway Safety BCA Tool provides default values for link capacity and free flow speed once the user selects the facility type of interest. The analyst should determine if the default values are representative of the facility under review and adjust them as necessary. Since facilities classified as 'urban other' or 'rural other' typically have low traffic volumes relative to the capacity, the Tool does not estimate reliability benefits for these facilities.

Reliability is a concept normally associated with peak periods where the traffic flow is impacted by incidents, including crashes. To determine the hours of buffer time saved per year, there is a need to select the number of analysis days per year and the number of peak periods per day. This Guide uses a default value of 260 analysis days per year (i.e., number of weekdays per year). The peak period duration (i.e., hours of peak traffic per day) is required to estimate roadway capacity, which is important for estimating buffer time. Typical peak period durations range from one to three hours, and this Guide assumes two hours of peak traffic per day as the default. If morning and evening peak periods have different characters (e.g., traffic volume and free flow speed), then it may be necessary to evaluate each period separately.

In addition, there is a need to determine if the value of time previously described for travel time benefits is also appropriate for buffer time benefits. The SHRP2 C-11 documents discuss the use of the reliability ratio. The reliability ratio is applied to the value of time to determine the value of an hour of buffer time saved. The SHRP2 C-11 report indicates this value may be different for personal and commercial buffer time benefits, and is generally set between 0.8 and 1.2. This Guide uses a default reliability ratio of 1.0 for personal trips and 1.2 for commercial trips. The value of 1.0 assumes the value of reliability in travel time is equal to the value in travel time for personal trips. The value of 1.2 assumes the value of reliability in travel time is 20 percent greater than the value in travel time for commercial trips.

For additional information on measuring reliability, refer to TRB's SHRP2 report, Development of Tools for Assessing Wider Economic Benefits of Transportation.[36] This report describes spreadsheet-based tools designed to help calculate a transportation project's impact on travel time reliability, market access, and intermodal connectivity. Chapter 7 provides examples that include estimates of travel time reliability using the methods included in the SHRP2 C-11 Reliability Module.

6.4 ESTIMATING VEHICLE OPERATING COST BENEFITS

The NHTSA report, *The Economic and Societal Impact Of Motor Vehicle Crashes*, provides a methodology for estimating fuel-related vehicle operating cost per crash for five roadway facility types.[11] The NHTSA approach is particularly useful for monetizing fuel-related vehicle operating cost per crash by crash severity and roadway facility type. Table 26 through Table 28 provide the NHTSA fuel-related vehicle operating cost in terms of gallons of fuel per crash and total value of fuel per crash (assuming the average cost of fuel is approximately $2.76 per gallon). Monetary values were updated using the CPI developed by the Bureau of Labor Statistics. The cost of fuel per injury crash is the same for any injury level (A-, B-, or C-level injury).

Table 26. Net increase in and cost of fuel consumption per fatal crash.[11]

Facility Type	Fuel (Gallons)	Value (2017 Dollars)
Urban Interstate/Expressway	1951	$5,394
Urban Arterial	504	$1,392
Urban Other	39	$107
Rural Interstate/Principal Arterials	294	$811
Rural Other	36	$101
Average All Roadway Types	376	$1,040

Table 27. Net increase in and cost of fuel consumption per injury crash.[11]

Facility Type	Fuel (Gallons)	Value (2017 Dollars)
Urban Interstate/Expressway	412	$1,140
Urban Arterial	112	$309
Urban Other	17	$47
Rural Interstate/Principal Arterials	54	$149
Rural Other	9	$26
Average All Roadway Types	81	$224

Table 28. Net increase in and cost of fuel consumption per PDO crash.[11]

Facility Type	Fuel (Gallons)	Value (2017 Dollars)
Urban Interstate/Expressway	351	$969
Urban Arterial	68	$187
Urban Other	10	$28
Rural Interstate/Principal Arterials	55	$153
Rural Other	8	$21
Average All Roadway Types	64	$176

Table 29 provides an example calculation for monetizing the change in fuel use that results from a change in crashes. This example uses the estimated annual change in crashes from the example in Table 23 and the fuel consumption per crash from Table 26 through Table 28. The example assumes the roadway facility is classified as a rural principal arterial and the average cost of fuel is $2.50 per gallon. For example, the fuel reduction associated with the reduction in fatal crashes is 0.032 crashes per year * 294 gallons per crash (from Table 26) = 9.41 gallons per year. For injury crashes, the relevant value is 54 gallons per crash for rural interstate/principal arterial. For PDO crashes, the relevant value is 55 gallons per crash for rural interstate/principal arterial.

Table 29. Example monetization of fuel-related vehicle operating cost for a project on a rural principal arterial (NHTSA methodology).

Crash Severity	Estimated Annual Reduction in Crashes (Table 23)	Gallons per Crash	Fuel Reduction (gallons)
K-Fatal	0.032	294	9.41
A-Injury	0.38	54	20.74
B-Injury	0.77	54	41.47
C-Injury	1.28	54	69.12
O-PDO	0.60	55	33.00
Total Annual Fuel Reduction (gallons)	--	--	**173.74**
Unit Value of Fuel (2017$/gallon)	--	--	**$2.50**
Total Annual Benefit	--	--	**$434**

Note: -- indicates not applicable.

6.5 ESTIMATING EMISSIONS BENEFITS

The NHTSA report, *The Economic and Societal Impact of Motor Vehicle Crashes*, provides a methodology to estimate emissions reductions for five roadway facility types based on reductions in crash frequency and severity.[11] Compared to other methods, the NHTSA approach is useful for estimating air emissions by crash severity and roadway facility type. Refer to Table 14 through Table 16 for the NHTSA monetized values of emissions per crash.

Table 30 provides an example calculation for monetizing the emissions benefit that results from a change in crashes. This example uses the estimated annual change in crashes from the example in Table 23 and the value of total emissions per crash from Table 14 through Table 16. The example assumes the roadway facility is classified as a rural principal arterial. For example, the total emissions reduction associated with the reduction in fatal crashes is 0.032 crashes per year * $379.50 per crash (from Table 14) = $12.14 per year. For injury crashes, the relevant value is $70.13 per crash for a rural principal arterial. For PDO crashes, the relevant value is $71.03 per crash for a rural principal arterial. This example uses the total emissions value to monetize the benefit of emissions reductions. Should an agency choose to monetize select emissions (e.g., only CO_2 and NO_X), then it would be necessary to replace the values of total emissions with the values of select emissions from Table 14 through Table 16.

Table 30. Example monetization of emissions for a project on a rural principal arterial (NHTSA methodology).

Crash Severity	Estimated Annual Reduction in Crashes (Table 23)	Value of Emissions per Crash	Emissions Reduction (Dollars)
K-Fatal	0.032	379.5	12.14
A-Injury	0.38	70.13	26.93
B-Injury	0.77	70.13	53.86
C-Injury	1.28	70.13	89.77
O-PDO	0.60	71.03	42.62
Total Annual Benefit	--	--	**$225**

Note: -- indicates not applicable.

6.6 CHAPTER SUMMARY

Chapter 6 describes how to estimate the direct and indirect safety benefits for a BCA. The chapter begins with a description of how to estimate the safety performance of a project alternative relative to the base condition (i.e., expected change in crash frequency by severity). It then describes how to estimate the operational and environmental benefits that result from a change in safety performance. Examples throughout the chapter illustrate the process of estimating benefits and then applying values from Chapter 4 to monetize the change in crashes, travel time, travel time reliability, vehicle operating costs, and emissions.

Key Takeaways from Chapter 6:

- Quality data and reliable methods are key to an accurate BCA and defensible results.
- The Highway Safety Manual provides reliable methods for estimating the expected change in safety performance (i.e., expected change in crash frequency and severity).
- Changes in safety performance impact travel time, vehicle operating costs, and air emissions. The NHTSA report, *The Economic and Societal Impact of Motor Vehicle Crashes*, provides a method to quantify the impact of crashes on travel time, fuel-related vehicle operating costs, and air emissions.(11)
- Changes in safety performance also impact travel time reliability. The SHRP2 C-11 Reliability Module provides a method to quantify the impact of crashes on travel time reliability.

7. PROJECT APPLICATIONS

Chapter 7 applies the methodologies explained in this Guide to various project examples. The examples illustrate a range of topics described in this Guide, including user-defined and default values, varying types of benefits and costs, the use of the discount rate, and various measures used to compare project alternatives. The examples in this chapter use hypothetical numbers. The purpose is to describe how to complete the calculations. Readers should not imply the numbers are indicative of any specific type of safety modification. The calculations are carried out in the Highway Safety BCA Tool following the guidance described in the previous chapters. The reader can download the tool and follow along with the calculations.

Chapter 7 At-A-Glance

Chapter 7 provides examples for the following scenarios:

- Section 7.1 provides an example BCA for a single countermeasure where two project alternatives are evaluated and compared to a base condition.
- Section 7.2 provides an example BCA for multiple countermeasures where a project with multiple improvements at the same location is evaluated and compared to a base condition. In this example, a CMF is available for the combined countermeasures (i.e., the combined safety effect of the multiple improvements is known).
- Section 7.3 provides an example BCA for multiple countermeasures where a project with multiple improvements at the same location is evaluated and compared to a base condition. In this example, a CMF is not available for the combined countermeasures (i.e., the combined safety effect of the multiple improvements should be estimated from individual CMFs).
- Section 7.4 provides an example BCA for multiple sites where an agency is considering similar projects at multiple locations (similar to a systemic improvement project). The example demonstrates how to assess the cost-effectiveness of each potential project location and prioritize locations within a fixed budget.

7.1 SINGLE COUNTERMEASURE EXAMPLE

7.1.1 Project Background

For this example, consider a scenario where an agency is considering the conversion of a two-way stop-controlled intersection along an urban arterial to a signalized intersection or a single-lane roundabout. This represents a project with a single countermeasure, but two alternatives, compared to the base condition. Alternative 1 evaluates the potential installation of a traffic signal, while Alternative 2 evaluates the potential construction of a roundabout. The base condition represents no change in existing conditions (i.e., maintaining the urban, two-lane, two-way stop-controlled intersection). The facility type best matches the 'urban arterial' category as described in section 6.3.

In this example, the free flow speed is 45 mph, the traffic volume in the peak period is 1,600 vehicles per hour per lane, and the peak period is two hours per day. Multiplying the 1,600 vehicles per hour per lane by one lane in one direction and again by the two hours of peak traffic per day, there is a total of 3,200 vehicles per direction during the peak period. As described in section 6.3, the analyst should define a segment over which to estimate the change in buffer time from a project. For signalized arterial corridors, it is reasonable to define the segment length between two or more signals. In this case, the analysis section is 0.8 miles, which includes the intersection of interest and the nearest adjacent signalized intersections.

The following sections provide further detail on the project location and facility conditions based on typical user input or default values from the Highway Safety BCA Tool.

7.1.2 Project Cost

Table 31 presents the service life, construction period, and project costs, including initial construction costs and annual maintenance costs, for the traffic signal and roundabout. The analyst selects an analysis period of 20 years as the lowest common multiple of the service lives. The construction period is entered in whole years, and it is assumed each alternative would be constructed within one year. Alternative 1 would require reconstruction after the useful service life, which would occur at the end of year 11 (10 years after construction). The reconstruction cost and annual maintenance costs are converted to present values, using the equation provided in Figure 9 (Chapter 5), a discount rate of 3.0 percent, and the expected service life of the project. Figure 16 shows the equation to convert annual costs for a given year to a present value. In this case, the equation shows the conversion of annual maintenance costs for year 21 for alternative 1. [Note this is year 20 after construction plus the one-year construction period.]

Table 31. Project costs for single countermeasure example, 2017 present value $.

Project Costs	Alternative 1 Traffic Signal	Alternative 2 Roundabout
Service life	10 years	20 years
Construction period	1 year	1 year
Initial project cost	$300,000	$900,000
Annual maintenance cost	$8,000	$0
Present value of reconstruction, rehabilitation, and maintenance costs	$320,356	$0
Total Present Value Cost	**$620,356**	**$900,000**

$$PV = \left(\frac{1}{(1+r)^t}\right) A_t = \left(\frac{1}{(1+0.03)^{21}}\right) \$8{,}000 = \$4{,}300$$

Figure 16. Equation. Example conversion of annual cost to present value cost for year 21 (Alternative 1).

Table 32 provides an amortization table to illustrate the calculation of present value costs from the annual maintenance costs for both alternatives. [Note the value of *t* for the equation in Figure 9, for this case, is the years after construction plus one to account for the one-year construction period of either alternative.]

Table 32. Amortization table for maintenance costs.

Years After Construction	Alternative 1	Alternative 2
1	$7,541	$0
2	$7,321	$0
3	$7,108	$0
4	$6,901	$0
5	$6,700	$0
6	$6,505	$0
7	$6,315	$0
8	$6,131	$0
9	$5,953	$0
10	$5,779	$0
11	$210,414	$0
12	$5,448	$0
13	$5,289	$0
14	$5,135	$0
15	$4,985	$0
16	$4,840	$0
17	$4,699	$0
18	$4,562	$0
19	$4,429	$0
20	$4,300	$0
Present Value	**$320,356**	**$0**

7.1.3 Estimated Annual Change in Crashes

Table 33 and Table 34 show the process to estimate the change in crashes between the base condition and build alternatives. All calculations are rounded to three decimals. In general, it is desirable to estimate the change in crashes and associated costs by severity. As such, the estimates are developed using the KABCO injury scale.

The estimated annual crashes under base conditions (column 2) represent the expected crashes using the EB method. In this case, the EB method combines the predicted crashes from an applicable, calibrated SPF (i.e., SPF for urban, two-lane, two-way stop-controlled intersection) and the observed crash history for the existing two-way stop-controlled intersection. While the average observed crash history is one option to estimate the long-term average safety performance under base conditions, the EB method provides a more reliable estimate, accounting for changes in traffic volume and regression-to-the-mean.

The third column shows the applicable, high-quality CMFs from the CMF Clearinghouse. For alternative 1, CMF ID 322 is selected to represent the safety effects of installing a traffic signal at an urban, two-way stop-controlled intersection. For alternative 2, CMF ID 233 is selected to represent the safety effects of constructing a roundabout at an urban, two-way stop-controlled intersection. Both CMFs are applicable to all crash types and all crash severities. While it is preferable to use CMFs that apply to the individual severity levels, this is limited by the availability of quality CMFs. As described in section 6.1, *Estimating Safety Benefits*, it may be necessary to assume the CMF for all crashes applies to K, A, B, C, and O crashes individually. This is the assumption in this example, recognizing the limitations (i.e., assuming the CMF is the same for each crash severity level may lead to over- or underestimating changes in specific severity levels).

The fourth column shows the estimated annual crashes with the given alternative. This is the product of the estimated annual crashes for base conditions (column 2) and the CMF (column 3). As an example, the estimated annual fatal crashes with alternative 1 is calculated as the product of the estimated annual fatal crashes under base conditions and the traffic signal CMF for fatal crashes (0.05 crashes per year * 0.95 = 0.048 crashes per year). The final column shows the estimated annual reduction in crashes, which is the difference between the estimated annual crashes under based conditions (column 2) and the estimated annual crashes with the alternative (column 4).

Table 33. Estimated change in crashes by severity for alternative 1 (traffic signal).

Crash Severity	Estimated Annual Crashes for Base Condition	CMF*	Estimated Annual Crashes with Alternative 1	Estimated Annual Reduction in Crashes
K-Fatal	0.050	0.950	0.048	0.003
A-Injury	0.670	0.950	0.637	0.034
B-Injury	0.790	0.950	0.751	0.040
C-Injury	3.670	0.950	3.487	0.184
O-PDO	8.670	0.950	8.237	0.434

* Assumes CMF is the same for all crash severity levels, which may over- or underestimate changes in specific crash severity levels.

Table 34. Estimated change in crashes by severity for alternative 2 (roundabout).

Crash Severity	Estimated Annual Crashes for Base Condition	CMF*	Estimated Annual Crashes with Alternative 2	Estimated Annual Reduction in Crashes
K-Fatal	0.050	0.610	0.031	0.020
A-Injury	0.670	0.610	0.409	0.261
B-Injury	0.790	0.610	0.482	0.308
C-Injury	3.670	0.610	2.239	1.431
O-PDO	8.670	0.610	5.289	3.381

* Assumes CMF is the same for all crash severity levels, which may over- or underestimate changes in specific crash severity levels.

7.1.4 Project Benefits

Project benefits are monetized using the estimated reductions in crashes by severity (Table 33 and Table 34). The NHTSA methods, described in Chapter 6, are used to calculate reductions in travel time delay, vehicle operating costs, and emissions. The SHRP2 Reliability Module adapted for use in the Tool is used to estimate travel time reliability benefits associated with a change in crashes. The sections below provide the detailed calculations for each of these benefits. In this example, the project location is along an urban arterial, which corresponds to the 'urban arterial' category in the NHTSA method.

7.1.4.1 Safety

Table 35 and Table 36 show the process to estimate the monetary project benefit based on the change in crashes from the base condition to the build alternative. This example uses the default monetary values of crashes by severity from Table 9 in section 4.1.1, *Value of Crashes*. The estimated annual safety benefit (column 4) is the product of the estimated annual change in crashes (column 2) and the crash value (column 3). As an example, the monetary benefit for the change in fatal crashes for alternative 1 is the product of the estimated annual change in fatal crashes and the default fatal crash value (0.003 crashes per year * $11,637,947 per crash = $29,095 per year). The total annual safety benefit related to the reduction in crashes is $88,670 for alternative 1 (traffic signal) and $691,625 for alternative 2 (roundabout).

Table 35. Monetary safety benefit for alternative 1 (traffic signal).

Crash Severity	Estimated Annual Reduction in Crashes	Crash Value (2017 Dollars)	Estimated Annual Safety Benefit
K-Fatal	0.003	$11,637,947	$29,095
A-Injury	0.034	$674,353	$22,591
B-Injury	0.040	$204,143	$8,064
C-Injury	0.184	$129,001	$23,672
O-PDO	0.434	$12,108	$5,249
TOTAL ANNUAL BENEFIT	--	--	**$88,670**

Note: -- indicates not applicable.

Table 36. Monetary safety benefit for alternative 2 (roundabout).

Crash Severity	Estimated Annual Reduction in Crashes	Crash Value (2017 Dollars)	Estimated Annual Safety Benefit
K-Fatal	0.020	$11,637,947	$226,940
A-Injury	0.261	$674,353	$176,208
B-Injury	0.308	$204,143	$62,896
C-Injury	1.431	$129,001	$184,639
O-PDO	3.381	$12,108	$40,941
TOTAL ANNUAL BENEFIT	--	--	**$691,625**

Note: -- indicates not applicable.

7.1.4.2 Travel Time

Table 37 and Table 38 show the process to estimate the monetary project benefit for travel time reductions due to the change in crashes from the base condition to the build alternative. This example uses the NHTSA delay factors from Table 24 and the NHTSA monetary value of time for 'urban arterial' from Table 10. The estimated annual delay reduction (column 4) is the product of the estimated annual change in crashes (column 2) and the NHTSA delay factor (column 3). As an example, the estimated annual delay reduction for A-injury crashes for alternative 1 is the product of the estimated annual change in A-injury crashes and the NHTSA delay factor for injury crashes (0.034 crashes per year * 68.56 hours per crash = 2.30 hours per year). The total annual travel time benefit related to the reduction in crashes is $1,127 for alternative 1 (traffic signal) and $8,794 for alternative 2 (roundabout).

Table 37. Monetary travel time benefit for alternative 1 (traffic signal).

Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Delay Factor (Hours per Crash)	Estimated Annual Delay Reduction (Hours)
K-Fatal	0.003	1258.26	3.15
A-Injury	0.034	68.56	2.30
B-Injury	0.040	68.56	2.71
C-Injury	0.184	68.56	12.58
O-PDO	0.434	49.94	21.65
Annual Delay Reduction (Hours)	--	--	**42.38**
Value of Time (Dollars per Hour)	--	--	**$26.60**
TOTAL ANNUAL BENEFIT (DOLLARS)	--	--	**$1,127.48**

Note: -- indicates not applicable.

Table 38. Monetary travel time benefit for alternative 2 (roundabout).

Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Delay Factor (Hours per Crash)	Estimated Annual Delay Reduction (Hours)
K-Fatal	0.020	1258.26	24.54
A-Injury	0.261	68.56	17.91
B-Injury	0.308	68.56	21.12
C-Injury	1.431	68.56	98.13
O-PDO	3.381	49.94	168.86
Annual Delay Reduction (Hours)	--	--	**330.57**
Value of Time (Dollars per Hour)	--	--	**$26.60**
TOTAL ANNUAL BENEFIT (DOLLARS)	--	--	**$8,794.36**

Note: -- indicates not applicable.

7.1.4.3 Travel Time Reliability

As discussed in Chapter 6, travel time reliability benefits associated with a change in crashes are estimated using the procedures developed for the SHRP2 Reliability Module spreadsheet tool. Table 39 summarizes the input values for the proposed alternatives, including user inputs and defaults from this Guide. Note the inputs for travel time reliability are the same for both alternatives. Using the Highway Safety BCA Tool, the reduction in annual weekday buffer time for alternative 1 is 49 hours, which equates to an annual value of $1,575 for travel time reliability benefits. The reduction in annual weekday buffer time for alternative 2 is 383 hours, which equates to an annual value of $12,238 for travel time reliability benefits.

Table 39. Travel time reliability inputs for single countermeasure example.

Variable	Value
Analysis Period (years)	20
Length of Construction Period (years)	1
Total Time Period (analysis period plus construction period)	21
Segment Length (miles)	0.8
Number of Lanes (2 for 2-lane roads; otherwise, number of lanes in one direction)	1
Free Flow Speed (mph)	45
Traffic Volume (total vehicles during peak period)	3,200
Link Capacity (total vehicles during peak period)	3,600
Hours of Peak Traffic per Day	2
Days of Analysis per Year	260
Annual Discount Rate (percent)	3%
Percent of Trucks in the Flow (percent)	5%
Fuel Cost (dollars/gallon)	$2.50
Personal Value of Time ($/hr.)	$26.06
Freight Value of Time ($/hr.)	$36.90
Calculated Combined Value of Time ($/hr.)	$26.60
Reliability Ratio Passenger	1
Reliability Ratio Freight	1.2

7.1.4.4 Vehicle Operating Cost

Table 40 and Table 41 show the process to estimate the monetary project benefit for changes in fuel use due to the change in crashes from the base condition to the build alternative. This example uses the NHTSA fuel factors from Table 26 through Table 28 for 'urban arterial,' assuming an average fuel cost of $2.50 per gallon. The estimated annual fuel reduction (column 4) is the product of the estimated annual change in crashes (column 2) and the NHTSA fuel factor (column 3). As an example, the estimated annual fuel reduction for PDO crashes for alternative 1 is the product of the estimated annual change in PDO crashes and the NHTSA fuel factor for PDO crashes (0.434 crashes per year * 68.00 gallons per crash = 29.48 gallons per year). The total annual fuel benefit related to the reduction in crashes is $149 for alternative 1 (traffic signal) and $1160 for alternative 2 (roundabout).

Table 40. Monetary fuel-related benefit for alternative 1 (traffic signal).

Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Fuel Factor (Gallons per Crash)	Estimated Annual Fuel Reduction (Gallons)
K-Fatal	0.003	504.00	1.26
A-Injury	0.034	112.00	3.75
B-Injury	0.040	112.00	4.42
C-Injury	0.184	112.00	20.55
O-PDO	0.434	68.00	29.48
Annual Fuel Reduction (Gallons)	--	--	**59.47**
Value of Fuel (Dollars per Gallon)	--	--	**$2.50**
Total Annual Benefit (Dollars)	--	--	**$148.67**

Note: -- indicates not applicable.

Table 41. Monetary fuel-related benefit for alternative 2 (roundabout).

Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Fuel Factor (Gallons per Crash)	Estimated Annual Fuel Reduction (Gallons)
K-Fatal	0.020	504.00	9.83
A-Injury	0.261	112.00	29.27
B-Injury	0.308	112.00	34.51
C-Injury	1.431	112.00	160.31
O-PDO	3.381	68.00	229.93
Annual Fuel Reduction (Gallons)	--	--	**463.83**
Value of Fuel (Dollars per Gallon)	--	--	**$2.50**
Total Annual Benefit (Dollars)	--	--	**$1,159.59**

Note: -- indicates not applicable.

7.1.4.5 Emissions

Table 42 and Table 43 show the process to estimate the monetary project benefit for emissions reductions due to the change in crashes from the base condition to the build alternative. This example uses the NHTSA values of total emissions from Table 14 through Table 16 for 'urban arterial.' The estimated annual emissions benefit (column 4) is the product of the estimated annual change in crashes (column 2) and the NHTSA values of total emissions (column 3). As an example, the estimated annual emissions benefit for PDO crashes for alternative 1 is the product of the estimated annual change in PDO crashes and the NHTSA value of total emissions for PDO crashes (0.434 crashes per year * $56.75 per crash = $24.60 per year). The total annual emissions benefit related to the reduction in crashes is $49 for alternative 1 (traffic signal) and $384 for alternative 2 (roundabout).

Table 42. Monetary emissions benefit for alternative 1 (traffic signal).

Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Value of Emissions (Dollars per Crash)	Estimated Annual Emissions Benefit (Dollars)
K-Fatal	0.003	$419.84	$1.05
A-Injury	0.034	$92.57	$3.07
B-Injury	0.040	$92.57	$3.62
C-Injury	0.184	$92.57	$16.83
O-PDO	0.434	$56.75	$24.60
Total Annual Benefit (Dollars)	--	--	**$49.17**

Note: -- indicates not applicable.

Table 43. Monetary emissions benefit for alternative 2 (roundabout).

Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Value of Emissions (Dollars per Crash)	Estimated Annual Emissions Benefit (Dollars)
K-Fatal	0.020	$419.84	$8.19
A-Injury	0.261	$92.57	$23.96
B-Injury	0.308	$92.57	$28.25
C-Injury	1.431	$92.57	$131.24
O-PDO	3.381	$56.75	$191.90
Total Annual Benefit (Dollars)	--	--	**$383.54**

Note: -- indicates not applicable.

7.1.5 BCA Result

Table 44 presents the results of the BCA. Table 45 and Table 46 provide the present value of project benefits for each category over the analysis period, using the equation provided in Figure 9 (Chapter 5), a discount rate of 3.0 percent, and the expected service life of the project. In this case, the value of *t* for the equation in Figure 9, is the years after construction plus one to account for the one-year period to construct either alternative. The service life of the traffic signal is 10 years and the service life of the roundabout is 20 years. Thus, to calculate the full net present value of the traffic signal over the same analysis period as the roundabout (i.e., 20 years), a replacement signal would be necessary in year 11. Table 45 shows how the benefits would continue to accrue in this period. Figure 17 shows the conversion of the annual safety benefit to a present value benefit for year 21 for alternative 1, using the equation from Figure 9. [Note this is year 20 after construction plus the one-year construction period.]

$$PV = \left(\frac{1}{(1+r)^t}\right) A_t = \left(\frac{1}{(1+0.03)^{21}}\right) \$88{,}670 = \$47{,}664$$

Figure 17. Equation. Example conversion of annual safety benefit to present value benefit for year 21 (alternative 1).

In this example, the benefits exceed the costs for alternative 1, with a net present value of $702,556 ($1,322,912 – $620,356). The net present value of alternative 2 is $9,418,036 ($10,318,036 – $900,000). Both alternatives provide positive net benefits and BCR greater than 1.0. As such, both alternatives are economically-justified. Alternative 2 costs more to deploy over the 20-year analysis period, but offers nearly eight times the amount of benefits as alternative 1. Thus, the BCR for alternative 2 is greater than the BCR for alternative 1 (11.46 compared to 2.13). A budget-constrained agency might find the higher efficiency of alternative 2, $11.46 returned for each dollar spent, more desirable that alternative 1.

Table 44. BCA results for single countermeasure example.

Project Costs and Benefits	Present Value Alternative 1 (Traffic Signal)	Present Value Alternative 2 (Roundabout)
Initial Cost	$300,000	$900,000
Present Value of Reconstruction, Rehabilitation, and Annual Maintenance Costs	$320,356	$0
Present Value of Costs (Dollars)	**$620,356**	**$900,000**
Present Value of Safety Benefit	$1,280,761	$9,989,932
Present Value of Travel Time Benefit	$16,286	$127,027
Present Value of Reliability Benefit	$23,475	$182,431
Present Value of Fuel Use Benefit	$2,147	$16,749
Present Value of Emissions Benefit	$243	$1,896
Present Value of Benefits (Dollars)	**$1,322,912**	**$10,318,036**
Net Present Value	**$702,556**	**$9,418,036**
Benefit-Cost Ratio	**2.13**	**11.46**

Table 45. Amortization table of project benefits for alternative 1 (traffic signal).

Years After Construction	Safety	Travel Time	Reliability	Fuel Use	Emissions
1	$83,580	$1,063	$1,575	$140	$16
2	$81,145	$1,032	$1,484	$136	$15
3	$78,782	$1,002	$1,441	$132	$15
4	$76,487	$973	$1,399	$128	$15
5	$74,260	$944	$1,358	$125	$14
6	$72,097	$917	$1,319	$121	$14
7	$69,997	$890	$1,280	$117	$13
8	$67,958	$864	$1,243	$114	$13
9	$65,979	$839	$1,207	$111	$13
10	$64,057	$815	$1,172	$107	$12
11	$62,191	$791	$1,138	$104	$12
12	$60,380	$768	$1,105	$101	$11
13	$58,621	$745	$1,072	$98	$11
14	$56,914	$724	$1,041	$95	$11
15	$55,256	$703	$1,011	$93	$10
16	$53,647	$682	$981	$90	$10
17	$52,084	$662	$953	$87	$10
18	$50,567	$643	$925	$85	$10
19	$49,094	$624	$898	$82	$9
20	$47,664	$606	$872	$80	$9
Present Value	**$1,280,761**	**$16,286**	**$23,475**	**$2,147**	**$243**

Table 46. Amortization table of project benefits for alternative 2 (roundabout).

Years After Construction	Safety	Travel Time	Reliability	Fuel Use	Emissions
1	$651,923	$8,290	$12,238	$1,093	$124
2	$632,935	$8,048	$11,536	$1,061	$120
3	$614,500	$7,814	$11,200	$1,030	$117
4	$596,602	$7,586	$10,874	$1,000	$113
5	$579,225	$7,365	$10,557	$971	$110
6	$562,354	$7,151	$10,249	$943	$107
7	$545,975	$6,942	$9,951	$915	$104
8	$530,073	$6,740	$9,661	$889	$101
9	$514,634	$6,544	$9,380	$863	$98
10	$499,644	$6,353	$9,106	$838	$95
11	$485,092	$6,168	$8,841	$813	$92
12	$470,963	$5,989	$8,584	$790	$89
13	$457,245	$5,814	$8,334	$767	$87
14	$443,928	$5,645	$8,091	$744	$84
15	$430,998	$5,480	$7,855	$723	$82
16	$418,444	$5,321	$7,627	$702	$79
17	$406,257	$5,166	$7,404	$681	$77
18	$394,424	$5,015	$7,189	$661	$75
19	$382,936	$4,869	$6,979	$642	$73
20	$371,782	$4,727	$6,776	$623	$71
Present Value	**$9,989,932**	**$127,027**	**$182,431**	**$16,749**	**$1,896**

7.2 MULTIPLE COUNTERMEASURE EXAMPLE #1

7.2.1 Project Background

For this example, consider a scenario where an agency is considering two countermeasures, paved shoulder widening (from 4-ft to 6-ft shoulders) and the installation of shoulder rumble strips, to address safety concerns related to run-off-road crashes along a rural, four-lane principal arterial. This represents a project with multiple countermeasures as part of one alternative compared to the base condition. The base condition represents no change in existing conditions (i.e., maintaining the rural, multilane road without shoulder widening or rumble strips). In this example, the free flow speed is 60 mph, the traffic volume in the peak period is 1,750 vehicles per hour per lane, and the peak period is two hours per day. Multiplying the 1,750 vehicles per hour per lane by two lanes in one direction and again by the two hours of peak traffic per day, there is a total of 7,000 vehicles per direction during the peak period. The improvements would extend for 9 miles, from milepost 1.0 to milepost 10.0. The facility type best matches the 'rural interstate / principal arterial' category as described in section 6.3. The following sections provide further detail on the project location and facility conditions based on typical user input or default values from the Highway Safety BCA Tool.

7.2.2 Project Cost

Table 47 presents the service life and project costs for the two countermeasures. The estimated initial construction cost is $100,000 per mile to widen the outside paved shoulder from 4 feet to 6 feet in both directions. The annual maintenance cost is negligible for the additional paved shoulder width. The estimated initial construction cost is $3,000 per mile to install rumble strips on the outside paved shoulder in both directions. The annual maintenance cost is negligible for the shoulder rumble strips.

Table 47. Project costs for multiple countermeasure example #1, 2017 present value $.

Project Costs	Countermeasure 1 Widen Shoulder	Countermeasure 2 Rumble Strips
Service life	7 years	7 years
Construction period	1 year	1 year
Initial project cost	$900,000	$27,000
Annual maintenance cost	$0	$0
Present value of maintenance costs	$0	$0
Total Present Value Cost	**$900,000**	**$27,000**

7.2.3 Estimated Annual Change in Crashes

Table 48 shows the process to estimate the change in crashes between the base condition and build alternative. All calculations are rounded to three decimals. In general, it is desirable to estimate the change in crashes and associated costs by severity. As such, the estimates are developed using the KABCO injury scale.

The estimated annual crashes under base conditions (column 2) represent the expected crashes using the EB method. The EB method combines predicted crashes from an applicable, calibrated SPF (i.e., SPF for rural, multilane roads) and the observed crash history for the existing rural, multilane road. While the average observed crash history is one option to estimate the long-term average safety performance under base conditions, the EB method provides a more reliable estimate, accounting for changes in traffic volume and regression-to-the-mean.

The third column shows the applicable, high-quality CMF from the CMF Clearinghouse. It is desirable to use a single CMF that represents the combined effect rather than using multiple CMFs to estimate the combined effect of two or more countermeasures. In this case, the CMF Clearinghouse provides a CMF for the combined countermeasure “install shoulder rumble strips and widen shoulder” (CMF ID 6669). This CMF applies to all crash types and all crash severities on rural, multilane roads. While it is preferable to use CMFs that apply to the individual severity levels, this is limited by the availability of quality CMFs. As described in section 6.1, *Estimating Safety Benefits*, it may be necessary to assume the CMF for all crashes applies to K, A, B, C, and O crashes individually. This is the assumption in this example, recognizing the limitations (i.e., assuming the CMF is the same for each crash severity level may lead to over- or underestimating changes in specific severity levels). Refer to 7.3, *Multiple Countermeasure Example #2*, for an example application of two CMFs to estimate the combined effect of multiple countermeasures.

The fourth column shows the estimated annual crashes with the given alternative. This is the product of the estimated annual crashes for base conditions (column 2) and the CMF (column 3). As an example, the estimated annual fatal crashes with both countermeasures is calculated as the product of the estimated annual fatal crashes under base conditions and the CMF for fatal crashes (0.100 crashes per year * 0.35 = 0.035 crashes per year). The final column shows the estimated annual reduction in crashes, which is the difference between the estimated annual crashes under base conditions (column 2) and the estimated annual crashes with both countermeasures (column 4).

Table 48. Estimated change in crashes by severity for multiple countermeasure example #1 (shoulder widening and shoulder rumble strips).

Crash Severity	Estimated Annual Crashes for Base Condition	CMF*	Estimated Annual Crashes with Both Countermeasures	Estimated Annual Reduction in Crashes
K-Fatal	0.100	0.350	0.035	0.065
A-Injury	0.500	0.350	0.175	0.325
B-Injury	0.800	0.350	0.280	0.520
C-Injury	1.400	0.350	0.490	0.910
O-PDO	2.200	0.350	0.770	1.430

* Assumes CMF is the same for all crash severity levels, which may over- or underestimate changes in specific crash severity levels.

7.2.4 Project Benefits

Project benefits are monetized using the estimated reductions in crashes by severity (Table 48). The NHTSA methods, described in Chapter 6, are used to calculate reductions in travel time delay, vehicle operating costs, and emissions. The SHRP2 Reliability Module adapted for use in the Tool is used to estimate travel time reliability benefits associated with a change in crashes. The sections below provide the detailed calculations for each of these benefits. In this example, the project location is a rural multilane road, which corresponds to the 'rural interstate / principal arterial' category in the NHTSA method.

7.2.4.1 Safety

Table 49 shows the process to estimate the monetary project benefit based on the change in crashes from the base condition to the build alternative. This example uses the default monetary values of crashes by severity from Table 9 in section 4.1.1, *Value of Crashes*. The estimated annual safety benefit (column 4) is the product of the estimated annual change in crashes (column 2) and the crash value (column 3). As an example, the monetary benefit for the change in fatal crashes for both countermeasures is the product of the estimated annual change in fatal crashes and the default fatal crash value (0.065 crashes per year * $11,637,947 per crash = $756,467 per year). The total annual safety benefit related to the reduction in crashes is $1,216,491 for both countermeasures.

Table 49. Monetary safety benefit for multiple countermeasure example #1 (shoulder widening and shoulder rumble strips).

Crash Severity	Estimated Annual Reduction in Crashes	Crash Value (2017 Dollars)	Estimated Annual Safety Benefit
K-Fatal	0.065	$11,637,947	$756,467
A-Injury	0.325	$674,353	$219,165
B-Injury	0.520	$204,143	$106,154
C-Injury	0.910	$129,001	$117,391
O-PDO	1.430	$12,108	$17,314
TOTAL ANNUAL BENEFIT	**--**	**--**	**$1,216,491**

Note: -- indicates not applicable.

7.2.4.2 Travel Time

Table 50 shows the process to estimate the monetary project benefit for travel time reductions due to the change in crashes from the base condition to the build alternative. This example uses the NHTSA delay factors from Table 24 and the NHTSA monetary value of time for 'rural interstate / principal arterial' from Table 10. The estimated annual delay reduction (column 4) is the product of the estimated annual change in crashes (column 2) and the NHTSA delay factor (column 3). As an example, the estimated annual delay reduction for A-injury crashes for both countermeasures is the product of the estimated annual change in A-injury crashes and the NHTSA delay factor for injury crashes (0.325 crashes per year * 207.68 hours per crash = 67.50 hours per year). The total annual travel time benefit related to the reduction in crashes is $19,978 for both countermeasures.

Table 50. Monetary travel time benefit for multiple countermeasure example #1 (shoulder widening and shoulder rumble strips).

Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Delay Factor (Hours per Crash)	Estimated Annual Delay Reduction (Hours)
K-Fatal	0.065	1780.31	115.72
A-Injury	0.325	207.68	67.50
B-Injury	0.520	207.68	107.99
C-Injury	0.910	207.68	188.99
O-PDO	1.430	146.25	209.14
Annual Delay Reduction (Hours)	--	--	**689.34**
Value of Time (Dollars per Hour)	--	--	**$28.98**
TOTAL ANNUAL BENEFIT (DOLLARS)	--	--	**$19,977.87**

Note: -- indicates not applicable.

7.2.4.3 Travel Time Reliability

As discussed in Chapter 6, travel time reliability benefits associated with a change in crashes are estimated using the procedures developed for the SHRP2 Reliability Module spreadsheet tool. Table 51 summarizes the input values for the proposed project, including user inputs and defaults from this Guide. Using the Highway Safety BCA Tool, the reduction in annual weekday buffer time for the project is 718 hours. This equates to an annual value of $24,962 for travel time reliability benefits.

Table 51. Travel time reliability inputs for multiple countermeasure example #1 (shoulder widening and shoulder rumble strips).

Variable	Value
Analysis Period (years)	7
Length of Construction Period (years)	1
Total Time Period (analysis period plus construction period)	8
Segment Length (miles)	9
Number of Lanes (2 for 2-lane roads; otherwise, number of lanes in one direction)	2
Free Flow Speed (mph)	60
Traffic Volume (total vehicles during peak period)	7,000
Link Capacity (total vehicles during peak period)	8,800
Hours of Peak Traffic per Day	2
Days of Analysis per Year	260
Annual Discount Rate (percent)	3%
Percent of Trucks in the Flow (percent)	20%
Fuel Cost (dollars/gallon)	$2.50
Personal Value of Time ($/hr.)	$26.25
Freight Value of Time ($/hr.)	$39.90
Calculated Combined Value of Time ($/hr.)	$28.98
Reliability Ratio Passenger	1
Reliability Ratio Freight	1.2

7.2.4.4 Vehicle Operating Cost

Table 52 shows the process to estimate the monetary project benefit for the change in fuel use due to the change in crashes from the base condition to the build alternative. This example uses the NHTSA fuel factors from Table 26 through Table 28 for 'rural interstate / principal arterial,' assuming an average fuel cost of $2.50 per gallon. The estimated annual fuel reduction (column 4) is the product of the estimated annual change in crashes (column 2) and the NHTSA fuel factor (column 3). As an example, the estimated annual fuel reduction for PDO crashes for both countermeasures is the product of the estimated annual change in PDO crashes and the

NHTSA fuel factor for PDO crashes (1.430 crashes per year * 55 gallons per crash = 78.65 gallons per year). The total annual fuel benefit related to the reduction in crashes is $481 for both countermeasures.

Table 52. Monetary fuel-related benefit for multiple countermeasure example #1 (shoulder widening and shoulder rumble strips).

Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Fuel Factor (Gallons per Crash)	Estimated Annual Fuel Reduction (Gallons)
K-Fatal	0.065	294.00	19.11
A-Injury	0.325	54.00	17.55
B-Injury	0.520	54.00	28.08
C-Injury	0.910	54.00	49.14
O-PDO	1.430	55.00	78.65
Annual Fuel Reduction (Gallons)	--	--	**192.53**
Value of Fuel (Dollars per Gallon)	--	--	**$2.50**
Total Annual Benefit (Dollars)	--	--	**$481.33**

Note: -- indicates not applicable.

7.2.4.5 Emissions

Table 53 shows the process to estimate the monetary project benefit for emissions reductions due to the change in crashes from the base condition to the build alternative. This example uses the NHTSA values of total emissions from Table 14 through Table 16 for 'rural interstate / principal arterial.' The estimated annual emissions benefit (column 4) is the product of the estimated annual change in crashes (column 2) and the NHTSA values of total emissions (column 3). As an example, the estimated annual emissions benefit for PDO crashes for both countermeasures is the product of the estimated annual change in PDO crashes and the NHTSA value of total emissions for PDO crashes (1.430 crashes per year * $70.34 per crash = $100.59 per year). The total annual emissions benefit related to the reduction in crashes is $246 for both countermeasures.

Table 53. Monetary emissions benefit for multiple countermeasure example #1 (shoulder widening and shoulder rumble strips).

Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Value of Emissions (Dollars per Crash)	Estimated Annual Emissions Benefit (Dollars)
K-Fatal	0.065	$375.79	$24.43
A-Injury	0.325	$69.43	$22.42
B-Injury	0.520	$69.43	$35.87
C-Injury	0.910	$69.43	$62.77
O-PDO	1.430	$70.34	$100.59
Total Annual Benefit (Dollars)	--	--	**$246.08**

Note: -- indicates not applicable.

7.2.5 BCA Result

Table 54 presents the results of the BCA. Table 55 provides the present value of project benefits for each category over the analysis period, using the equation provided in Figure 9 (Chapter 5), a discount rate of 3.0 percent, and the expected service life of the project. In this case, the value of *t* for the equation in Figure 9 is the years after construction plus one to account for the one-year period to construct the project. The service life of the combined countermeasure is 7 years. Figure 18 shows the conversion of the annual safety benefit to a present value benefit for year 8, using the equation from Figure 9. [Note this is year 7 after construction plus the one-year construction period.]

$$PV = \left(\frac{1}{(1+r)^t}\right) A_t = \left(\frac{1}{(1+0.03)^8}\right) \$1{,}216{,}491 = \$960{,}309$$

Figure 18. Equation. Example conversion of annual safety benefit to present value benefit for year 8 (multiple countermeasure example #1).

In this example, the benefits exceed the costs, with a net present value of $6,711,717 ($7,638,717 – $927,000) and a BCR of 8.24 ($7,638,717 / $927,000). The combination of shoulder widening and installing shoulder rumble strips provides positive net benefits and BCR greater than 1.0. As such, the proposed project is economically-justified. The BCR indicates a return of $8.24 for each dollar spent.

Table 54. BCA results for multiple countermeasure example #1.

Project Costs and Benefits	Present Value
Initial Cost	$927,000
Present Value of Annual Maintenance Costs	$0
Present Value of Costs (Dollars)	**$927,000**
Present Value of Safety Benefit	$7,358,333
Present Value of Travel Time Benefit	$120,842
Present Value of Reliability Benefit	$156,250
Present Value of Fuel Use Benefit	$2,911
Present Value of Emissions Benefit	$380
Present Value of Benefits (Dollars)	**$7,638,717**
Net Present Value	**$6,711,717**
Benefit-Cost Ratio	**8.24**

Table 55. Amortization table of project benefits for multiple countermeasure example #1 (shoulder widening and shoulder rumble strips).

Years After Construction	Safety	Travel Time	Reliability	Fuel Use	Emissions
1	$1,146,659	$18,831	$24,962	$454	$59
2	$1,113,262	$18,283	$23,530	$440	$57
3	$1,080,836	$17,750	$22,844	$428	$56
4	$1,049,356	$17,233	$22,179	$415	$54
5	$1,018,792	$16,731	$21,533	$403	$53
6	$989,118	$16,244	$20,906	$391	$51
7	$960,309	$15,771	$20,297	$380	$50
Present Value	**$7,358,333**	**$120,842**	**$156,250**	**$2,911**	**$380**

7.3 MULTIPLE COUNTERMEASURE EXAMPLE #2

7.3.1 Project Background

For this example, consider a scenario where an agency is considering two countermeasures, paved shoulder widening (from 1-ft to 4-ft shoulders) and implementation of a safety edge, to address safety concerns related to run-off-road crashes along a rural, two-lane minor arterial. This represents a project with multiple countermeasures as part of one alternative compared to the base condition. The base condition represents no change in existing conditions (i.e., maintaining the rural, two-lane road without shoulder widening or safety edge). The facility type best matches the 'rural other' category as described in section 6.3. The following sections provide further detail on the project location and facility conditions based on typical user input or default values from the Highway Safety BCA Tool.

7.3.2 Project Cost

Table 56 presents the service life and project costs for the combined countermeasure. The estimated initial construction cost is $150,000 per mile to widen the paved shoulder from 1 foot to 4 feet and implement the safety edge in both directions. The improvements would extend for 5 miles, from milepost 1.0 to milepost 6.0. The annual maintenance cost is negligible for the additional paved shoulder width and safety edge.

Table 56. Project costs for multiple countermeasure example #2 (shoulder widening and safety edge), 2017 present value $.

Project Costs	Combined Countermeasure
Service life	7 years
Construction period	1 year
Initial project cost	$750,000
Annual maintenance cost	$0
Present value of maintenance costs	$0
Total Present Value Cost	**$750,000**

7.3.3 Estimated Annual Change in Crashes

In general, it is desirable to estimate the change in crashes and associated costs by severity. As such, the estimates are developed using the KABCO injury scale. Further, it is desirable to use a single CMF that represents the combined effect rather than using multiple CMFs to estimate the combined effect of two or more countermeasures. In this case, the CMF Clearinghouse does not provide a single CMF for the combined countermeasure (shoulder widening and safety edge). Instead, there is a need to estimate the combined countermeasure effect using multiple CMFs and the method described in section 6.1.3, *Estimating the Safety Benefit of Multiple Countermeasures*.

Table 57 shows the applicable CMFs from the CMF Clearinghouse for the two individual countermeasures. For shoulder widening, CMF ID 4821 and CMF ID 4822 are selected to represent the safety effects of widening the shoulder on a rural, two-lane, minor arterial. CMF ID 4821 applies to all crash types and PDO crashes. CMF ID 4822 applies to all crash types and KABC crash severity levels. For implementing the safety edge, CMF ID 4335 and CMF ID 4323 are selected to represent the safety effects of implementing the safety edge on rural, two-lane roads. CMF ID 4335 is applicable to all crash types and PDO crashes. CMF ID 4323 is applicable to all crash types and KABC crash severity levels. While it is preferable to use CMFs that apply to the individual severity levels, this is limited by the availability of quality CMFs. As described in section 6.1, *Estimating Safety Benefits*, it may be necessary to assume the CMF for injury crashes applies to K, A, B, and C crashes individually. This is the assumption in this example, recognizing the limitations (i.e., assuming the CMF is the same for each crash severity level may lead to over- or underestimating changes in specific severity levels).

Table 57. Estimated combined CMF by severity for multiple countermeasure example #2 (shoulder widening and safety edge).

Crash Severity	Applicable CMF for Shoulder Widening*	Applicable CMF for Safety Edge*	Method to Estimate Combined Effect	Estimated Combined CMF
K	0.86	0.84	Dominant Common Residuals	0.76
A	0.86	0.84	Dominant Common Residuals	0.76
B	0.86	0.84	Dominant Common Residuals	0.76
C	0.86	0.84	Dominant Common Residuals	0.76
O	0.91	0.96	Dominant Common Residuals	0.88

* Assumes CMF is the same for all crash severity levels, which may over- or underestimate changes in specific crash severity levels.

In this example, the CMFs by severity apply to the same crash types and are less than 1.0. The agency assumes some overlap in the effect of the two countermeasures (i.e., safety edge provides additional benefit, but the full effect of the safety edge is not realized due to overlap with shoulder widening). Given these assumptions, the Dominant Common Residuals method is appropriate to estimate the combined effect unless the Dominant Effect method produces a greater benefit, in which case the Dominant Effect method would be most appropriate.

Figure 19 shows the application of the Dominant Common Residuals method to estimate the combined effect of shoulder widening and safety edge on fatal and injury crashes (K, A, B, and C severity levels) for this example. Figure 20 shows the application of the Dominant Common Residuals method to estimate the combined effect of shoulder widening and safety edge on PDO crashes for this example. Since the Dominant Common Residuals method produces a greater benefit than the Dominant Effect method for both severity levels, these are the combined CMFs used in the example as shown in Table 58. Refer to section 6.1.3, *Estimating the Safety Benefit of Multiple Countermeasures*, for further details on estimating the combined effect of multiple countermeasures.

$$\mathrm{CMF_t} = (\mathrm{CMF_1} * \mathrm{CMF_2})^{CMF_1} = (0.84 * 0.86)^{0.84} = 0.761$$

Figure 19. Equation. Dominant common residuals method for estimating the combined effect of shoulder widening and safety edge on KABC crashes.

$$\mathrm{CMF_t} = (\mathrm{CMF_1} * \mathrm{CMF_2})^{CMF_1} = (0.91 * 0.96)^{0.91} = 0.884$$

Figure 20. Equation. Dominant common residuals method for estimating the combined effect of shoulder widening and safety edge on PDO crashes.

Table 58 shows the process to estimate the change in crashes between the base condition and build alternative. All calculations are rounded to three decimals. The estimated annual crashes under base conditions (column 2) represent the expected crashes using the EB method. In this case, the EB method combines the predicted crashes from an applicable, calibrated SPF (i.e., SPF for rural, two-lane roads) and the observed crash history for the existing rural, two-lane road. While the average observed crash history is one option to estimate the long-term average safety performance under base conditions, the EB method provides a more reliable estimate, accounting for changes in traffic volume and regression-to-the-mean.

The third column shows the estimated combined CMFs by severity from Table 57. The fourth column shows the estimated annual crashes with both countermeasures. This is the product of the estimated annual crashes for base conditions (column 2) and the CMF for the combined countermeasure (column 3). As an example, the estimated annual fatal crashes with both countermeasures is calculated as the product of the estimated annual fatal crashes under base conditions and the CMF for fatal crashes (0.050 crashes per year * 0.761 = 0.038 crashes per year). The final column shows the estimated annual reduction in crashes, which is the difference between the estimated annual crashes under base conditions (column 2) and the estimated annual crashes with both countermeasures (column 4).

Table 58. Estimated change in crashes by severity for multiple countermeasure example #2 (shoulder widening and safety edge).

Crash Severity	Estimated Annual Crashes for Base Condition	CMF	Estimated Annual Crashes with Both Countermeasures	Estimated Annual Reduction in Crashes
K-Fatal	0.050	0.761	0.038	0.012
A-Injury	0.150	0.761	0.114	0.036
B-Injury	0.200	0.761	0.152	0.048
C-Injury	0.300	0.761	0.228	0.072
O-PDO	1.300	0.884	1.150	0.150

7.3.4 Project Benefits

Project benefits are monetized using the estimated reductions in crashes by severity (Table 58). The NHTSA methods, described in Chapter 6, are used to calculate reductions in travel time delay, vehicle operating costs, and emissions. The sections below provide the detailed calculations for each of these benefits. In this example, the project location is a rural, two-lane, minor arterial, which corresponds to the 'rural other' category in the NHTSA method. The Reliability Module is not intended for facilities classified as 'urban other' or 'rural other.' As such, the reliability benefits are $0 in this example.

7.3.4.1 Safety

Table 59 shows the process to estimate the monetary project benefit based on the change in crashes from the base condition to the build alternative. This example uses the default monetary values of crashes by severity from Table 9 in section 4.1.1, *Value of Crashes*. The estimated annual safety benefit (column 4) is the product of the estimated annual change in crashes (column 2) and the crash value (column 3). As an example, the monetary benefit for the change in fatal crashes for both countermeasures is the product of the estimated annual change in fatal crashes and the default fatal crash value (0.012 crashes per year * $11,637,947 per crash = $139,085 per year). The total annual safety benefit related to the reduction in crashes is $184,093 for both countermeasures.

Table 59. Monetary safety benefit for multiple countermeasure example #2 (shoulder widening and safety edge).

Crash Severity	Estimated Annual Reduction in Crashes	Crash Value (2017 Dollars)	Estimated Annual Safety Benefit
K-Fatal	0.012	$11,637,947	$139,085
A-Injury	0.036	$674,353	$24,178
B-Injury	0.048	$204,143	$9,759
C-Injury	0.072	$129,001	$9,250
O-PDO	0.150	$12,108	$1,821
Total Annual Benefit	**--**	**--**	**$184,093**

Note: -- indicates not applicable.

7.3.4.2 Travel Time

Table 60 shows the process to estimate the monetary project benefit for travel time reductions due to the change in crashes from the base condition to the build alternative. This example uses the NHTSA delay factors from Table 24 and the NHTSA monetary value of time for roads classified as 'rural other' from Table 10. The estimated annual delay reduction (column 4) is the product of the estimated annual change in crashes (column 2) and the NHTSA delay factor (column 3). As an example, the estimated annual delay reduction for A-injury crashes for both countermeasures is the product of the estimated annual change in A-injury crashes and the NHTSA delay factor for injury crashes (0.04 crashes per year * 13.86 hours per crash = 0.55 hours per year). The total annual travel time benefit related to the reduction in crashes is $135 for both countermeasures.

Table 60. Monetary travel time benefit for multiple countermeasure example #2 (shoulder widening and safety edge).

Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Delay Factor (Hours per Crash)	Estimated Annual Delay Reduction (Hours)
K-Fatal	0.012	104.82	1.25
A-Injury	0.036	13.86	0.50
B-Injury	0.048	13.86	0.66
C-Injury	0.072	13.86	0.99
O-PDO	0.150	10.33	1.55
Annual Delay Reduction (Hours)	--	--	**4.96**
Value of Time (Dollars per Hour)	--	--	**$27.57**
TOTAL ANNUAL BENEFIT (DOLLARS)	--	--	**$136.72**

Note: -- indicates not applicable.

7.3.4.3 Travel Time Reliability

As discussed in Chapter 6, travel time reliability benefits associated with a change in crashes are estimated using the procedures developed for the SHRP2 Reliability Module spreadsheet tool. The SHRP2 Reliability Module is not intended for facilities classified as 'urban other' or 'rural other' because these facilities typically have low traffic volumes relative to the capacity and the reliability benefits are negligible. In this example, the reliability benefits are $0 because the facility type is classified as 'rural other.'

7.3.4.4 Vehicle Operating Cost

Table 61 shows the process to estimate the monetary project benefit for the change in fuel use due to the change in crashes from the base condition to the build alternative. This example uses the NHTSA fuel factors for roads classified as 'rural other' from Table 26 through Table 28, assuming an average fuel cost of $2.50 per gallon. The estimated annual fuel reduction (column 4) is the product of the estimated annual change in crashes (column 2) and the NHTSA fuel factor (column 3). As an example, the estimated annual fuel reduction for PDO crashes for both countermeasures is the product of the estimated annual change in PDO crashes and the NHTSA fuel factor for PDO crashes (0.150 crashes per year * 8 gallons per crash = 1.20 gallons per year). The total annual fuel benefit related to the reduction in crashes is $8 for both countermeasures.

Table 61. Monetary fuel-related benefit for multiple countermeasure example #2 (shoulder widening and safety edge).

Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Fuel Factor (Gallons per Crash)	Estimated Annual Fuel Reduction (Gallons)
K-Fatal	0.012	36.00	0.43
A-Injury	0.036	9.00	0.32
B-Injury	0.048	9.00	0.43
C-Injury	0.072	9.00	0.65
O-PDO	0.150	8.00	1.20
Annual Fuel Reduction (Gallons)	--	--	**3.03**
Value of Fuel (Dollars per Gallon)	--	--	**$2.50**
Total Annual Benefit (Dollars)	--	--	**$7.58**

Note: -- indicates not applicable.

7.3.4.5 Emissions

Table 62 shows the process to estimate the monetary project benefit for emissions reductions due to the change in crashes from the base condition to the build alternative. This example uses the NHTSA values of total emissions for roads classified as 'rural other' from Table 14 through Table 16. The estimated annual emissions benefit (column 4) is the product of the estimated annual change in crashes (column 2) and the NHTSA values of total emissions (column 3). As an example, the estimated annual emissions benefit for PDO crashes for both countermeasures is the product of the estimated annual change in PDO crashes and the NHTSA value of total emissions for PDO crashes (0.16 crashes per year * $8.55 per crash = $1.37 per year). The total annual emissions benefit related to the reduction in crashes is $3 for both countermeasures.

Table 62. Monetary emissions benefit for multiple countermeasure example #2 (shoulder widening and safety edge).

Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Value of Emissions (Dollars per Crash)	Estimated Annual Emissions Benefit (Dollars)
K-Fatal	0.012	$40.84	$0.49
A-Injury	0.036	$10.29	$0.37
B-Injury	0.048	$10.29	$0.49
C-Injury	0.072	$10.29	$0.73
O-PDO	0.150	$8.55	$1.29
Total Annual Benefit (Dollars)	--	--	**$3.36**

Note: -- indicates not applicable.

7.3.5 BCA Result

Table 63 presents the results of the BCA. Table 64 provides the present value of project benefits for each category over the analysis period, using the equation provided in Figure 9 (Chapter 5), a discount rate of 3.0 percent, and the expected service life of the project. In this case, the value of t for the equation in Figure 9 is the years after construction plus one to account for the one-year period to construct the project. The service life of the combined countermeasure is 7 years. Figure 21 shows the conversion of the annual safety benefit to a present value benefit for year 8, using the equation from Figure 9. [Note this is year 7 after construction plus the one-year construction period.]

$$PV = \left(\frac{1}{(1+r)^t}\right) A_t = \left(\frac{1}{(1+0.03)^8}\right) \$184{,}093 = \$145{,}325$$

Figure 21. Equation. Example conversion of annual safety benefit to present value benefit for year 7 (multiple countermeasure example #2).

In this example, the benefits exceed the costs, with a net present value of $364,422 $1,114,422 – $750,000) and a BCR of 1.49 ($1,114,422 / $750,000). The combination of shoulder widening and safety edge provides positive net benefits and BCR greater than 1.0. As such, the proposed project is economically-justified. The BCR indicates a return of $1.49 for each dollar spent.

Table 63. BCA results for multiple countermeasure example #2.

Project Costs and Benefits	Present Value
Initial Cost	$750,000
Present Value of Annual Maintenance Costs	$0
Present Value of Costs (Dollars)	**$750,000**
Present Value of Safety Benefit	$1,113,545
Present Value of Travel Time Benefit	$827
Present Value of Reliability Benefit	$0
Present Value of Fuel Use Benefit	$46
Present Value of Emissions Benefit	$4
Present Value of Benefits (Dollars)	**$1,114,422**
Net Present Value	**$364,422**
Benefit-Cost Ratio	**1.49**

Table 64. Amortization table of project benefits for multiple countermeasure example #2 (shoulder widening and safety edge).

Years After Construction	Safety	Travel Time	Reliability	Fuel Use	Emissions
1	$173,525	$129	$0	$7	$0.67
2	$168,471	$125	$0	$7	$0.65
3	$163,564	$121	$0	$7	$0.63
4	$158,800	$118	$0	$7	$0.61
5	$154,175	$115	$0	$6	$0.59
6	$149,684	$111	$0	$6	$0.58
7	$145,325	$108	$0	$6	$0.56
Present Value	**$1,113,545**	**$827**	**$0**	**$46**	**$4**

7.4 MULTIPLE SITES (SYSTEMIC) EXAMPLE

7.4.1 Project Background

For this example, consider a scenario where an agency is considering a systemic approach to address curve-related crashes along rural, two-lane roads. Specifically, the agency identified curve-related fatal and serious injury crashes as the focus crash type, and rural, two-lane local roads as the focus facility type based on cross-tabulations when developing their Strategic Highway Safety Plan. Further analysis of these crashes reveals that small curve radius (i.e., curve radius less than or equal to 500 feet) is a primary indicator of the potential for future fatal and serious injury crashes on rural, two-lane curves. Based on the analysis, the agency selects a low-cost signing improvement to warn drivers of the sharp curves. The package includes a combination of advance horizontal alignment and advisory speed signs. This represents a project with multiple potential sites.

The agency has allocated $5,000 for the curve signing project and would like to identify the most effective use of funds. To select the optimal list of sites for the systemic sign project, the agency should estimate the BCR for each curve and then rank the sites by BCR from high to low. The sites with the highest BCR values will receive the sign package until funds are exhausted. There are 10 potential sites in this example and the base condition represents no change in existing conditions (i.e., maintaining the rural, two-lane curve without signing). The facility type best matches the ‘rural other’ category as described in section 6.3. Table 65 shows the annual average daily traffic (AADT), length, and radius of each curve. The following sections provide further detail on the project location and facility conditions based on typical user input or default values from the Highway Safety BCA Tool.

Table 65. Summary of curves for multiple sites example.

Curve	AADT (vehicles per day)	Length of Curve (miles)	Radius of Curve (feet)
1	6500	0.07	350
2	7500	0.1	500
3	5000	0.06	450
4	7000	0.11	500
5	5500	0.06	250
6	7500	0.19	450
7	10000	0.23	500
8	6000	0.07	250
9	8500	0.17	400
10	9500	0.21	500

7.4.2 Project Cost

Table 66 presents the service life and project costs for the systemic sign package. The sign package would be the same for each curve, consisting of one advance horizontal alignment sign and one advisory speed sign in each direction. The estimated initial construction cost is $1000 per curve. The annual maintenance cost is negligible, the service life is 5 years, and the construction period is 0 years.

Table 66. Project cost for multiple sites example, 2017 present value $.

Project Costs	Systemic Sign Package
Service life	5 years
Construction period	0 years
Initial project cost (per curve)	$1,000
Annual maintenance cost	$0
Present value of maintenance costs	$0
Total Present Value Cost (per curve)	**$1,000**

7.4.3 Estimated Annual Change in Crashes

Given the random location of fatal and serious injury crashes on horizontal curves, the agency decided the observed crash history was not a good representation of the long-term average crashes for any given curve. Instead, the agency employed the Highway Safety Manual Part C Predictive Method to estimate the safety performance of each curve under base conditions. Figure 22 shows the SPF to predict crashes for a rural, two-lane road segment under base conditions. For example, if the AADT is 7,500 vehicles per day, and the segment length is 0.1 miles, then the equation predicts 0.2004 crashes per year.

$$N_{SPF\ Base} = AADT * L * 10^{-6} * e^{-0.312}$$

Figure 22. Equation. SPF for rural, two-lane base segments.

Where:

$N_{SPF\ Base}$ = annual predicted crashes under base conditions.

AADT = traffic volume (vehicles per day).

L = segment length (miles).

The base condition is a tangent section, while the segments of interest are all curves. As such, it is necessary to apply a CMF to adjust the base SPF prediction according to the site-specific conditions. Figure 23 shows the equation to estimate the CMF for horizontal curves based on the length and radius of curve. For example, if the curve length is 0.1 miles, the radius is 500 feet, and there is no spiral transition, then the equation produces a CMF of 2.03, indicating this curve is expected to experience 203 percent more crashes than a similar tangent section.

$$\mathrm{CMF}_{\mathrm{curve}} = \frac{1.55 * L_c + \frac{80.2}{R} - 0.012 * S}{1.55 * L_c}$$

Figure 23. Equation. CMF for horizontal curve on rural, two-lane road.

Where:

CMF_{curve} = CMF for the specific horizontal curve geometry.

L_c = length of curve (miles).

R = radius of curve (feet).

S = presence of spiral transition (1 if yes; 0 otherwise).

Table 67 shows the predicted total crashes for the 10 potential curves included in this example. The fifth column presents the SPF prediction for the base condition, assuming a tangent section, based on the equation from Figure 22. The sixth column presents the CMF for each specific curve based on the curve geometry and the equation from Figure 23. The last column is the product of the base SPF prediction and the CMF, representing the predicted total crashes for each curve.

Table 67. Estimated long-term average crashes for multiple sites example.

Curve	AADT (vehicles per day)	Curve Length (miles)	Curve Radius (feet)	Base SPF Prediction (Total Crashes)	CMF	Predicted Total Crashes
1	6500	0.07	350	0.1216	3.11	0.3784
2	7500	0.1	500	0.2004	2.03	0.4078
3	5000	0.06	450	0.0802	2.92	0.2339
4	7000	0.11	500	0.2057	1.94	0.3992
5	5500	0.06	250	0.0882	4.45	0.3924
6	7500	0.19	450	0.3807	1.61	0.6111
7	10000	0.23	500	0.6145	1.45	0.8910
8	6000	0.07	250	0.1122	3.96	0.4439
9	8500	0.17	400	0.3861	1.76	0.6799
10	9500	0.21	500	0.5330	1.49	0.7957

The next step is to estimate the number of crashes by severity level so the agency can apply the crash costs and NHTSA method presented in chapter 4 and chapter 6. To do so, the agency applies crash severity proportions to the predicted total crashes as shown in the Highway Safety Manual.(7) The crash severity proportions for similar rural, two-lane roads are 1.3 percent fatal crashes, 5.4 percent A-injury crashes, 10.9 percent B-injury crashes, 14.5 percent C-injury crashes, and 67.9 percent PDO crashes. Table 68 shows the estimated crashes by severity after applying the crash severity proportions to the predicted total crashes.

Table 68. Estimated crashes by severity for multiple sites example.

Curve	Adjusted SPF Prediction (Total Crashes)	K (1.3%)	A (5.4%)	B (10.9%)	C (14.5%)	O (67.9%)
1	0.3784	0.0049	0.0204	0.0412	0.0549	0.2569
2	0.4078	0.0053	0.0220	0.0445	0.0591	0.2769
3	0.2339	0.0030	0.0126	0.0255	0.0339	0.1588
4	0.3992	0.0052	0.0216	0.0435	0.0579	0.2711
5	0.3924	0.0051	0.0212	0.0428	0.0569	0.2664
6	0.6111	0.0079	0.0330	0.0666	0.0886	0.4149
7	0.8910	0.0116	0.0481	0.0971	0.1292	0.6050
8	0.4439	0.0058	0.0240	0.0484	0.0644	0.3014
9	0.6799	0.0088	0.0367	0.0741	0.0986	0.4617
10	0.7957	0.0103	0.0430	0.0867	0.1154	0.5403

Table 69 shows the process to estimate the change in crashes between the condition with and without the systemic sign package. All calculations are rounded to four decimals because of the small values. In general, it is desirable to estimate the change in crashes and associated costs by severity. As such, the estimates are developed using the KABCO injury scale.

The estimated annual crashes under base conditions (column 3) represent the predicted crashes using the Highway Safety Manual Part C Method as explained previously. The fourth column shows the applicable CMF from the CMF Clearinghouse. It is desirable to use a single CMF that represents the combined effect rather than using multiple CMFs to estimate the combined effect of two or more countermeasures. In this case, the CMF Clearinghouse provides CMFs for the combined countermeasure "install combination horizontal alignment / advisory speed signs" (CMF ID 73 and CMF ID 74). Both CMFs are applicable to curves on rural, two-lane roads. CMF ID 73 applies to all crash types and KABC crash severity levels. CMF ID 74 applies to all crash types and PDO crashes. While it is preferable to use CMFs that apply to the individual severity levels, this is limited by the availability of quality CMFs. As described in section 6.1, *Estimating Safety Benefits*, it may be necessary to assume the CMF for injury crashes applies to K, A, B, and C crashes individually. This is the assumption in this example, recognizing the limitations (i.e., assuming the CMF is the same for each crash severity level may lead to over- or underestimating changes in specific severity levels).

The sixth column shows the estimated annual crashes with the systemic sign package. This is the product of the estimated annual crashes for base conditions (column 3) and the CMF (column 4). As an example, the estimated annual fatal crashes for curve 1 with the systemic sign package is calculated as the product of the estimated annual fatal crashes under base conditions and the CMF for fatal crashes (0.0049 crashes per year * 0.87 = 0.0043 crashes per year). The final column shows the estimated annual reduction in crashes, which is the difference between the estimated annual crashes under base conditions (column 3) and the estimated annual crashes with the systemic sign package (column 6). This approach assumes the predicted safety performance of the base condition, estimated using the Highway Safety Manual Part C Method, represents the condition without the systemic sign package. Analysts should exercise caution in applying CMFs from the Clearinghouse to the predicted or expected crashes from the Highway Safety Manual Part C Method because SPFs are developed for a specific base condition.

Table 69. Estimated change in crashes by severity for multiple sites example.

Curve	Crash Severity	Estimated Annual Crashes for Base Condition	CMF*	CMF ID	Estimated Annual Crashes With Countermeasure	Estimated Annual Reduction in Crashes
1	K	0.0049	0.87	73	0.0043	0.0006
1	A	0.0204	0.87	73	0.0177	0.0027
1	B	0.0412	0.87	73	0.0358	0.0054
1	C	0.0549	0.87	73	0.0478	0.0071
1	O	0.2569	0.71	74	0.1824	0.0745
2	K	0.0053	0.87	73	0.0046	0.0007
2	A	0.0220	0.87	73	0.0191	0.0029
2	B	0.0445	0.87	73	0.0387	0.0058
2	C	0.0591	0.87	73	0.0514	0.0077
2	O	0.2769	0.71	74	0.1966	0.0803
3	K	0.0030	0.87	73	0.0026	0.0004
3	A	0.0126	0.87	73	0.0110	0.0016
3	B	0.0255	0.87	73	0.0222	0.0033
3	C	0.0339	0.87	73	0.0295	0.0044
3	O	0.1588	0.71	74	0.1127	0.0461
4	K	0.0052	0.87	73	0.0045	0.0007
4	A	0.0216	0.87	73	0.0188	0.0028
4	B	0.0435	0.87	73	0.0378	0.0057
4	C	0.0579	0.87	73	0.0504	0.0075
4	O	0.2711	0.71	74	0.1925	0.0786
5	K	0.0051	0.87	73	0.0044	0.0007
5	A	0.0212	0.87	73	0.0184	0.0028
5	B	0.0428	0.87	73	0.0372	0.0056
5	C	0.0569	0.87	73	0.0495	0.0074
5	O	0.2664	0.71	74	0.1891	0.0773

Curve	Crash Severity	Estimated Annual Crashes for Base Condition	CMF*	CMF ID	Estimated Annual Crashes With Countermeasure	Estimated Annual Reduction in Crashes
6	K	0.0079	0.87	73	0.0069	0.0010
6	A	0.0330	0.87	73	0.0287	0.0043
6	B	0.0666	0.87	73	0.0579	0.0087
6	C	0.0886	0.87	73	0.0771	0.0115
6	O	0.4149	0.71	74	0.2946	0.1203
7	K	0.0116	0.87	73	0.0101	0.0015
7	A	0.0481	0.87	73	0.0418	0.0063
7	B	0.0971	0.87	73	0.0845	0.0126
7	C	0.1292	0.87	73	0.1124	0.0168
7	O	0.6050	0.71	74	0.4296	0.1754
8	K	0.0058	0.87	73	0.0050	0.0008
8	A	0.0240	0.87	73	0.0209	0.0031
8	B	0.0484	0.87	73	0.0421	0.0063
8	C	0.0644	0.87	73	0.0560	0.0084
8	O	0.3014	0.71	74	0.2140	0.0874
9	K	0.0088	0.87	73	0.0077	0.0011
9	A	0.0367	0.87	73	0.0319	0.0048
9	B	0.0741	0.87	73	0.0645	0.0096
9	C	0.0986	0.87	73	0.0858	0.0128
9	O	0.4617	0.71	74	0.3278	0.1339
10	K	0.0103	0.87	73	0.0090	0.0013
10	A	0.0430	0.87	73	0.0374	0.0056
10	B	0.0867	0.87	73	0.0754	0.0113
10	C	0.1154	0.87	73	0.1004	0.0150
10	O	0.5403	0.71	74	0.3836	0.1567

* Assumes CMF is the same for all crash severity levels, which may over- or underestimate changes in specific crash severity levels.

7.4.4 Project Benefits

Project benefits are monetized using the estimated reductions in crashes by severity (Table 69). The NHTSA methods, described in Chapter 6, are used to calculate reductions in travel time delay, vehicle operating costs, and emissions. The sections below provide the detailed calculations for each of these benefits. In this example, the potential project locations are all curves on rural, two-lane collectors, which correspond to the 'rural other' category in the NHTSA method. The Reliability Module is not intended for facilities classified as 'urban other' or 'rural other.' As such, the reliability benefits are $0 in this example.

7.4.4.1 Safety

Table 70 shows the process to estimate the monetary project benefit based on the change in crashes from the base condition to the condition with the systemic sign package. This example uses the default monetary values of crashes by severity from Table 9 in section 4.1.1, *Value of Crashes*. The estimated annual safety benefit (column 5) is the product of the estimated annual change in crashes (column 3) and the crash value (column 4). As an example, the monetary benefit for the change in PDO crashes for curve 1 is the product of the estimated annual change in PDO crashes and the default PDO crash value (0.0745 crashes per year * $12,108 per crash = $902 per year). The total annual safety benefit related to the reduction in crashes is the sum of the annual benefit across the five severity levels for each curve. For curve 1, the total annual benefit is $11,724 ($6,983 + $1,821 + $1,102 + $916 + $902).

Table 70. Monetary safety benefit for multiple sites example.

Curve	Crash Severity	Estimated Annual Reduction in Crashes	Crash Value (2017 Dollars)	Estimated Annual Safety Benefit (Dollars)
1	K	0.0006	$11,637,947	$6,983
1	A	0.0027	$674,353	$1,821
1	B	0.0054	$204,143	$1,102
1	C	0.0071	$129,001	$916
1	O	0.0745	$12,108	$902
Curve 1 Total	--	0.0903	--	$11,724
2	K	0.0007	$11,637,947	$8,147
2	A	0.0029	$674,353	$1,956
2	B	0.0058	$204,143	$1,184
2	C	0.0077	$129,001	$993
2	O	0.0803	$12,108	$972
Curve 2 Total	--	0.0974	--	$13,252
3	K	0.0004	$11,637,947	$4,655
3	A	0.0016	$674,353	$1,079
3	B	0.0033	$204,143	$674
3	C	0.0044	$129,001	$568
3	O	0.0461	$12,108	$558
Curve 3 Total	--	0.0558	--	$7,534
4	K	0.0007	$11,637,947	$8,147
4	A	0.0028	$674,353	$1,888
4	B	0.0057	$204,143	$1,164
4	C	0.0075	$129,001	$968
4	O	0.0786	$12,108	$952
Curve 4 Total	--	0.0953	--	$13,118
5	K	0.0007	$11,637,947	$8,147
5	A	0.0028	$674,353	$1,888
5	B	0.0056	$204,143	$1,143
5	C	0.0074	$129,001	$955
5	O	0.0773	$12,108	$936
Curve 5 Total	--	0.0938	--	$13,069
6	K	0.0010	$11,637,947	$11,638
6	A	0.0043	$674,353	$2,900
6	B	0.0087	$204,143	$1,776
6	C	0.0115	$129,001	$1,484
6	O	0.1203	$12,108	$1,457
Curve 6 Total	--	0.1458	--	$19,254

Curve	Crash Severity	Estimated Annual Reduction in Crashes	Crash Value (2017 Dollars)	Estimated Annual Safety Benefit (Dollars)
7	K	0.0015	$11,637,947	$17,457
7	A	0.0063	$674,353	$4,248
7	B	0.0126	$204,143	$2,572
7	C	0.0168	$129,001	$2,167
7	O	0.1754	$12,108	$2,124
Curve 7 Total	--	0.2126	--	$28,569
8	K	0.0008	$11,637,947	$9,310
8	A	0.0031	$674,353	$2,090
8	B	0.0063	$204,143	$1,286
8	C	0.0084	$129,001	$1,084
8	O	0.0874	$12,108	$1,058
Curve 8 Total	--	0.1060	--	$14,829
9	K	0.0011	$11,637,947	$12,802
9	A	0.0048	$674,353	$3,237
9	B	0.0096	$204,143	$1,960
9	C	0.0128	$129,001	$1,651
9	O	0.1339	$12,108	$1,621
Curve 9 Total	--	0.1622	--	$21,271
10	K	0.0013	$11,637,947	$15,129
10	A	0.0056	$674,353	$3,776
10	B	0.0113	$204,143	$2,307
10	C	0.0150	$129,001	$1,935
10	O	0.1567	$12,108	$1,897
Curve 10 Total	--	0.1899	--	$25,045

Note: -- indicates not applicable.

7.4.4.2 Travel Time

Table 71 shows the process to estimate the monetary project benefit for travel time reductions due to the change in crashes from the base condition to the condition with the systemic sign package. This example uses the NHTSA delay factors from Table 24 and the NHTSA monetary value of time ($27.57 per hour) for roads classified as 'rural other' from Table 10. The estimated annual delay reduction (column 5) is the product of the estimated annual change in crashes (column 3) and the NHTSA delay factor (column 4). As an example, the estimated annual delay reduction for B-injury crashes for curve 1 is the product of the estimated annual change in B-injury crashes and the NHTSA delay factor for injury crashes (0.0054 crashes per year * 13.86 hours per crash = 0.0748 hours per year).

The estimated annual travel time benefit (column 6) is the product of the estimated annual delay reduction (column 5) and the value of time ($27.57 per hour) for roads classified as 'rural other' from Table 10. As an example, the estimated annual travel time benefit for B-injury crashes for curve 1 is the product of the estimated annual delay reduction for B-injury crashes and the value of time (0.0748 hours per year * $27.57 per hour = $2.06 per year). The total annual travel time benefit related to the reduction in crashes is the sum of the annual benefit across the five severity levels for each curve. For curve 1, the total annual travel time benefit is $28.76 ($1.73 + $1.03 + $2.06 + $2.71 + $21.22).

Table 71. Monetary travel time benefit for multiple sites example.

Curve	Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Delay Factor (Hours per Crash)	Estimated Annual Delay Reduction (Hours)	Estimated Annual Travel Time Benefit (Dollars)
1	K	0.0006	104.82	0.0629	$1.73
1	A	0.0027	13.86	0.0374	$1.03
1	B	0.0054	13.86	0.0748	$2.06
1	C	0.0071	13.86	0.0984	$2.71
1	O	0.0745	10.33	0.7696	$21.22
Curve 1 Total	--	0.0903	--	1.0431	$28.76
2	K	0.0007	104.82	0.0734	$2.02
2	A	0.0029	13.86	0.0402	$1.11
2	B	0.0058	13.86	0.0804	$2.22
2	C	0.0077	13.86	0.1067	$2.94
2	O	0.0803	10.33	0.8295	$22.87
Curve 2 Total	--	0.0974	--	1.1302	$31.16
3	K	0.0004	104.82	0.0419	$1.16
3	A	0.0016	13.86	0.0222	$0.61
3	B	0.0033	13.86	0.0457	$1.26
3	C	0.0044	13.86	0.0610	$1.68
3	O	0.0461	10.33	0.4762	$13.13
Curve 3 Total	--	0.0558	--	0.6470	$17.84
4	K	0.0007	104.82	0.0734	$2.02
4	A	0.0028	13.86	0.0388	$1.07
4	B	0.0057	13.86	0.0790	$2.18
4	C	0.0075	13.86	0.1040	$2.87
4	O	0.0786	10.33	0.8119	$22.39
Curve 4 Total	--	0.0953	--	1.1071	$30.52
5	K	0.0007	104.82	0.0734	$2.02
5	A	0.0028	13.86	0.0388	$1.07
5	B	0.0056	13.86	0.0776	$2.14
5	C	0.0074	13.86	0.1026	$2.83
5	O	0.0773	10.33	0.7985	$22.01
Curve 5 Total	--	0.0938	--	1.0909	$30.08
6	K	0.001	104.82	0.1048	$2.89
6	A	0.0043	13.86	0.0596	$1.64
6	B	0.0087	13.86	0.1206	$3.32
6	C	0.0115	13.86	0.1594	$4.39
6	O	0.1203	10.33	1.2427	$34.26
Curve 6 Total	--	0.1458	--	1.6871	$46.51

Curve	Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Delay Factor (Hours per Crash)	Estimated Annual Delay Reduction (Hours)	Estimated Annual Travel Time Benefit (Dollars)
7	K	0.0015	104.82	0.1572	$4.33
7	A	0.0063	13.86	0.0873	$2.41
7	B	0.0126	13.86	0.1746	$4.81
7	C	0.0168	13.86	0.2328	$6.42
7	O	0.1754	10.33	1.8119	$49.95
Curve 7 Total	--	0.2126	--	2.4639	$67.93
8	K	0.0008	104.82	0.0839	$2.31
8	A	0.0031	13.86	0.0430	$1.18
8	B	0.0063	13.86	0.0873	$2.41
8	C	0.0084	13.86	0.1164	$3.21
8	O	0.0874	10.33	0.9028	$24.89
Curve 8 Total	--	0.106	--	1.2334	$34.01
9	K	0.0011	104.82	0.1153	$3.18
9	A	0.0048	13.86	0.0665	$1.83
9	B	0.0096	13.86	0.1331	$3.67
9	C	0.0128	13.86	0.1774	$4.89
9	O	0.1339	10.33	1.3832	$38.13
Curve 9 Total	--	0.1622	--	1.8755	$51.71
10	K	0.0013	104.82	0.1363	$3.76
10	A	0.0056	13.86	0.0776	$2.14
10	B	0.0113	13.86	0.1566	$4.32
10	C	0.015	13.86	0.2079	$5.73
10	O	0.1567	10.33	1.6187	$44.63
Curve 10 Total	--	0.1899	--	2.1971	$60.57

7.4.4.3 Travel Time Reliability

A reliable trip is one with little trip time variation. Travel on roads classified as 'rural other,' such as those in this example, is typically reliable because traffic volume is low relative to the capacity, and travel time is predictable. Even during peak periods, trips along these routes are predictable. Since the reliability benefits for these projects are minimal, these benefits are excluded from the BCA.

7.4.4.4 Vehicle Operating Cost

Table 72 shows the process to estimate the monetary project benefit for the change in fuel use due to the change in crashes from the base condition to the condition with the systemic sign package. This example uses the NHTSA fuel factors for roads classified as 'rural other' from Table 26 through Table 28, assuming an average fuel cost of $2.50 per gallon. The estimated annual fuel reduction (column 5) is the product of the estimated annual change in crashes (column 3) and the NHTSA fuel factor (column 4). As an example, the estimated annual fuel reduction for PDO crashes for curve 1 is the product of the estimated annual change in PDO crashes for curve 1 and the NHTSA fuel factor for PDO crashes (0.0745 crashes per year * 8 gallons per crash = 0.5960 gallons per year).

The estimated annual fuel use benefit (column 6) is the product of the estimated annual fuel reduction (column 5) and the value of fuel (assumed $2.50 per gallon for this example). As an example, the estimated annual fuel use benefit for PDO crashes for curve 1 is the product of the estimated annual fuel reduction for PDO crashes and the value of fuel (0.5960 gallons per year * $2.50 per gallon = $1.49 per year). The total annual fuel use benefit related to the reduction in crashes is the sum of the annual benefit across the five severity levels for each curve. For curve 1, the total annual fuel use benefit is $1.89 ($0.05 + $0.06 + $0.12 + $0.16 + $1.49).

Table 72. Monetary fuel-related benefit for multiple sites example.

Curve	Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Fuel Factor (Gallons per Crash)	Estimated Annual Fuel Reduction (Gallons)	Estimated Annual Fuel Use Benefit (Dollars)
1	K	0.0006	36	0.0216	$0.05
1	A	0.0027	9	0.0243	$0.06
1	B	0.0054	9	0.0486	$0.12
1	C	0.0071	9	0.0639	$0.16
1	O	0.0745	8	0.5960	$1.49
Curve 1 Total	--	0.0903	--	0.7544	$1.89
2	K	0.0007	36	0.0252	$0.06
2	A	0.0029	9	0.0261	$0.07
2	B	0.0058	9	0.0522	$0.13
2	C	0.0077	9	0.0693	$0.17
2	O	0.0803	8	0.6424	$1.61
Curve 2 Total	--	0.0974	--	0.8152	$2.04
3	K	0.0004	36	0.0144	$0.04
3	A	0.0016	9	0.0144	$0.04
3	B	0.0033	9	0.0297	$0.07
3	C	0.0044	9	0.0396	$0.10
3	O	0.0461	8	0.3688	$0.92
Curve 3 Total	--	0.0558	--	0.4669	$1.17
4	K	0.0007	36	0.0252	$0.06
4	A	0.0028	9	0.0252	$0.06
4	B	0.0057	9	0.0513	$0.13
4	C	0.0075	9	0.0675	$0.17
4	O	0.0786	8	0.6288	$1.57
Curve 4 Total	--	0.0953	--	0.7980	$2.00

Curve	Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Fuel Factor (Gallons per Crash)	Estimated Annual Fuel Reduction (Gallons)	Estimated Annual Fuel Use Benefit (Dollars)
5	K	0.0007	36	0.0252	$0.06
5	A	0.0028	9	0.0252	$0.06
5	B	0.0056	9	0.0504	$0.13
5	C	0.0074	9	0.0666	$0.17
5	O	0.0773	8	0.6184	$1.55
Curve 5 Total	--	0.0938	--	0.7858	$1.96
6	K	0.001	36	0.0360	$0.09
6	A	0.0043	9	0.0387	$0.10
6	B	0.0087	9	0.0783	$0.20
6	C	0.0115	9	0.1035	$0.26
6	O	0.1203	8	0.9624	$2.41
Curve 6 Total	--	0.1458	--	1.2189	$3.05
7	K	0.0015	36	0.0540	$0.14
7	A	0.0063	9	0.0567	$0.14
7	B	0.0126	9	0.1134	$0.28
7	C	0.0168	9	0.1512	$0.38
7	O	0.1754	8	1.4032	$3.51
Curve 7 Total	--	0.2126	--	1.7785	$4.45
8	K	0.0008	36	0.0288	$0.07
8	A	0.0031	9	0.0279	$0.07
8	B	0.0063	9	0.0567	$0.14
8	C	0.0084	9	0.0756	$0.19
8	O	0.0874	8	0.6992	$1.75
Curve 8 Total	--	0.106	--	0.8882	$2.22
9	K	0.0011	36	0.0396	$0.10
9	A	0.0048	9	0.0432	$0.11
9	B	0.0096	9	0.0864	$0.22
9	C	0.0128	9	0.1152	$0.29
9	O	0.1339	8	1.0712	$2.68
Curve 9 Total	--	0.1622	--	1.3556	$3.39
10	K	0.0013	36	0.0468	$0.12
10	A	0.0056	9	0.0504	$0.13
10	B	0.0113	9	0.1017	$0.25
10	C	0.015	9	0.1350	$0.34
10	O	0.1567	8	1.2536	$3.13
Curve 10 Total	--	0.1899	--	1.5875	$3.97

7.4.4.5 Emissions

Table 73 shows the process to estimate the monetary project benefit for emissions reductions due to the change in crashes from the base condition to the condition with the systemic sign package. This example uses the NHTSA values of total emissions for roads classified as 'rural other' from Table 14 through Table 16. The estimated annual emissions benefit (column 5) is the product of the estimated annual change in crashes (column 3) and the NHTSA values of total emissions (column 4). As an example, the estimated annual emissions benefit for PDO crashes for curve 1 is the product of the estimated annual change in PDO crashes for curve 1 and the NHTSA value of total emissions for PDO crashes (0.0745 crashes per year * $8.55 per crash = $0.64 per year). The total annual emissions benefit related to the reduction in crashes is the sum of the annual benefit across the five severity levels for each curve. For curve 1, the total annual emissions benefit is $0.82 ($0.02 + $0.03 + $0.06 + $0.07 + $0.64).

Table 73. Monetary emissions benefit for multiple sites example.

Curve	Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Value of Emissions (Dollars per Crash)	Estimated Annual Emissions Benefit (Dollars)
1	K	0.0006	$40.84	$0.02
1	A	0.0027	$10.29	$0.03
1	B	0.0054	$10.29	$0.06
1	C	0.0071	$10.29	$0.07
1	O	0.0745	$8.55	$0.64
Curve 1 Total	--	0.0903	--	$0.82
2	K	0.0007	$40.84	$0.03
2	A	0.0029	$10.29	$0.03
2	B	0.0058	$10.29	$0.06
2	C	0.0077	$10.29	$0.08
2	O	0.0803	$8.55	$0.69
Curve 2 Total	--	0.0974	--	$0.88
3	K	0.0004	$40.84	$0.02
3	A	0.0016	$10.29	$0.02
3	B	0.0033	$10.29	$0.03
3	C	0.0044	$10.29	$0.05
3	O	0.0461	$8.55	$0.39
Curve 3 Total	--	0.0558	--	$0.51
4	K	0.0007	$40.84	$0.03
4	A	0.0028	$10.29	$0.03
4	B	0.0057	$10.29	$0.06
4	C	0.0075	$10.29	$0.08
4	O	0.0786	$8.55	$0.67
Curve 4 Total	--	0.0953	--	$0.87

Curve	Crash Severity	Estimated Annual Reduction in Crashes	NHTSA Value of Emissions (Dollars per Crash)	Estimated Annual Emissions Benefit (Dollars)
5	K	0.0007	$40.84	$0.03
5	A	0.0028	$10.29	$0.03
5	B	0.0056	$10.29	$0.06
5	C	0.0074	$10.29	$0.08
5	O	0.0773	$8.55	$0.66
Curve 5 Total	--	0.0938	--	$0.85
6	K	0.001	$40.84	$0.04
6	A	0.0043	$10.29	$0.04
6	B	0.0087	$10.29	$0.09
6	C	0.0115	$10.29	$0.12
6	O	0.1203	$8.55	$1.03
Curve 6 Total	--	0.1458	--	$1.32
7	K	0.0015	$40.84	$0.06
7	A	0.0063	$10.29	$0.06
7	B	0.0126	$10.29	$0.13
7	C	0.0168	$10.29	$0.17
7	O	0.1754	$8.55	$1.50
Curve 7 Total	--	0.2126	--	$1.93
8	K	0.0008	$40.84	$0.03
8	A	0.0031	$10.29	$0.03
8	B	0.0063	$10.29	$0.06
8	C	0.0084	$10.29	$0.09
8	O	0.0874	$8.55	$0.75
Curve 8 Total	--	0.106	--	$0.96
9	K	0.0011	$40.84	$0.04
9	A	0.0048	$10.29	$0.05
9	B	0.0096	$10.29	$0.10
9	C	0.0128	$10.29	$0.13
9	O	0.1339	$8.55	$1.14
Curve 9 Total	--	0.1622	--	$1.47
10	K	0.0013	$40.84	$0.05
10	A	0.0056	$10.29	$0.06
10	B	0.0113	$10.29	$0.12
10	C	0.015	$10.29	$0.15
10	O	0.1567	$8.55	$1.34
Curve 10 Total	--	0.1899	--	$1.72

7.4.5 BCA Result

Table 74 presents a summary of the annual monetary benefits for each curve for the various categories, including safety, travel time, reliability, vehicle operating cost, and emissions. These values represent the sum of annual benefits across the five severity levels from the previous tables in this section.

Table 74. Summary of annual monetary benefits for multiple sites example.

Curve	Safety	Travel Time	Reliability	Fuel Use	Emissions
1	$11,724	$29	--	$2	$0.82
2	$13,252	$31	--	$2	$0.88
3	$7,534	$18	--	$1	$0.51
4	$13,118	$31	--	$2	$0.87
5	$13,069	$30	--	$2	$0.85
6	$19,254	$47	--	$3	$1.32
7	$28,569	$68	--	$4	$1.93
8	$14,829	$34	--	$2	$0.96
9	$21,271	$52	--	$3	$1.47
10	$25,045	$61	--	$4	$1.72

Note: -- indicates reliability benefits are excluded from this example.

Table 75 presents the results of the BCA for each curve, indicating the present value benefit for each category (i.e., safety, travel time, reliability, vehicle operating cost, and emissions), the total present value benefit (all categories combined), and the benefit-cost ratio. While not shown in the table, the present value cost is $1,000 for each candidate curve. Table 76 provides the present value of project benefits for each category over the analysis period, using the equation provided in Figure 9 (Chapter 5), a discount rate of 3.0 percent, and the expected service life of the project. In this case, the value of t for the equation in Figure 9 is the years after construction because the construction period is 0 years. The service life of the systemic sign package is 5 years. Figure 24 shows the conversion of the annual safety benefit to a present value benefit for curve 1 in year 5, using the equation from Figure 9. [Note this is year 5 after construction because the construction period is 0 years.]

$$PV = \left(\frac{1}{(1+r)^t}\right) A_t = \left(\frac{1}{(1+0.03)^5}\right) \$11{,}724 = \$10{,}113$$

Figure 24. Equation. Example conversion of annual safety benefit to present value benefit for curve 1 in year 5 (multiple sites example).

In this example, the benefits exceed the costs for each curve as indicated by a BCR greater than 1.0. While the systemic sign package is economically-justified for each candidate curve, the agency has allocated $5,000 for the systemic signing project. As such, the agency can apply the sign package to five of the candidate curves. The most economically-efficient and effective list of curves includes those with the five highest BCR values: curves 6, 7, 8, 9, and 10.

Table 75. BCA results for multiple sites example.

Curve	Safety	Travel Time	Reliability	Fuel Use	Emissions	Total Present Value Benefit	Benefit-Cost Ratio
1	$53,692	$132	--	$9	$4	$53,836	53.84
2	$60,689	$143	--	$9	$4	$60,845	60.85
3	$34,502	$82	--	$5	$2	$34,591	34.59
4	$60,075	$140	--	$9	$4	$60,227	60.23
5	$59,850	$138	--	$9	$4	$60,001	60.00
6	$88,177	$213	--	$14	$6	$88,410	88.41
7	$130,835	$311	--	$20	$9	$131,176	131.18
8	$67,912	$156	--	$10	$4	$68,082	68.08
9	$97,414	$237	--	$16	$7	$97,673	97.67
10	$114,698	$277	--	$18	$8	$115,002	115.00

Table 76. Amortization table of project benefits for multiple sites example.

Curve	Years After Construction	Safety	Travel Time	Reliability	Fuel Use	Emissions
1	1	$11,382	$28	--	$2	$0.79
1	2	$11,051	$27	--	$2	$0.77
1	3	$10,729	$26	--	$2	$0.75
1	4	$10,416	$26	--	$2	$0.73
1	5	$10,113	$25	--	$2	$0.71
2	1	$12,866	$30	--	$2	$0.86
2	2	$12,491	$29	--	$2	$0.83
2	3	$12,127	$29	--	$2	$0.81
2	4	$11,774	$28	--	$2	$0.79
2	5	$11,431	$27	--	$2	$0.76
3	1	$7,314	$17	--	$1	$0.49
3	2	$7,101	$17	--	$1	$0.48
3	3	$6,894	$16	--	$1	$0.46
3	4	$6,694	$16	--	$1	$0.45
3	5	$6,499	$15	--	$1	$0.44

4	1	$12,735	$30	--	$2	$0.84
4	2	$12,365	$29	--	$2	$0.82
4	3	$12,004	$28	--	$2	$0.79
4	4	$11,655	$27	--	$2	$0.77
4	5	$11,315	$26	--	$2	$0.75
5	1	$12,688	$29	--	$2	$0.83
5	2	$12,318	$28	--	$2	$0.80
5	3	$11,960	$28	--	$2	$0.78
5	4	$11,611	$27	--	$2	$0.76
5	5	$11,273	$26	--	$2	$0.74
6	1	$18,693	$45	--	$3	$1.28
6	2	$18,149	$44	--	$3	$1.25
6	3	$17,620	$43	--	$3	$1.21
6	4	$17,107	$41	--	$3	$1.17
6	5	$16,609	$40	--	$3	$1.14
7	1	$27,736	$66	--	$4	$1.87
7	2	$26,929	$64	--	$4	$1.82
7	3	$26,144	$62	--	$4	$1.76
7	4	$25,383	$60	--	$4	$1.71
7	5	$24,643	$59	--	$4	$1.66
8	1	$14,397	$33	--	$2	$0.94
8	2	$13,978	$32	--	$2	$0.91
8	3	$13,570	$31	--	$2	$0.88
8	4	$13,175	$30	--	$2	$0.86
8	5	$12,791	$29	--	$2	$0.83
9	1	$20,651	$50	--	$3	$1.43
9	2	$20,050	$49	--	$3	$1.39
9	3	$19,466	$47	--	$3	$1.34
9	4	$18,899	$46	--	$3	$1.31
9	5	$18,348	$45	--	$3	$1.27
10	1	$24,315	$59	--	$4	$1.67
10	2	$23,607	$57	--	$4	$1.62
10	3	$22,920	$55	--	$4	$1.58
10	4	$22,252	$54	--	$4	$1.53
10	5	$21,604	$52	--	$3	$1.48

8. COMMUNICATING BCA RESULTS

A thorough BCA quantifies the costs and benefits of project alternatives. Decision-makers can use the BCA results, along with available budgets and other information, to determine if a project is worth the investment and then decide which investment alternatives will move forward. While BCA results can identify the most economically-efficient alternatives, the effort is unproductive unless decision-makers use the results to inform decisions. As such, there is a need to communicate BCA results to decision-makers and potentially other audiences. Further, there is a need to present the technical information clearly and concisely.

The effort to conduct a BCA is unproductive unless decision-makers use the results to inform decisions.

Chapter 8 At-A-Glance

Chapter 8 is divided into three sections:

- Section 8.1 identifies several considerations for presenting BCA results.
- Section 8.2 presents several examples for communicating BCA results.
- Section 8.3 provides a summary of the chapter.

8.1 CONSIDERATIONS FOR PRESENTING BCA RESULTS

In general, BCA results may include measures such as present value costs and benefits, BCR, net present value, and return on investment. The following are factors to consider when preparing to present this information and other relevant details to communicate the BCA results to stakeholders:

- **Target audience**: determine the target audience and tailor the information accordingly; non-technical audiences may require simplified versions and graphical depictions of the results.
- **Economic measures**: determine the need to display and convey one or more economic measures such as present value costs and benefits, BCR, net present value, and return on investment.
- **Project details**: determine the need to include information about the project alternatives such as the project objectives, project limits, and type of improvement(s).
- **Analysis details**: indicate the type of analysis (e.g., comparison of a single alternative with the base condition, or comparison of multiple alternatives) and timeframe of analysis (potential future project or a completed project).

- **Assumptions**: determine the need to indicate analysis parameters and assumptions such as the analysis period, discount rate, and itemized costs. For potential future projects, the analysis may include several assumptions. For completed projects, there are fewer assumptions because the project costs and benefits are known. In either case, it is important to state the assumptions and sources of information.
- **Preferred alternative**: if there are multiple alternatives, then it may be appropriate to identify, and possibly highlight, the preferred alternative (e.g., the most cost-effective or cost-efficient alternative). Further, it may be appropriate to demonstrate how the various alternatives compare to the preferred alternative.
- **Display format**: determine the need for tabular and/or graphical displays.

Depending on the target audience, and purpose of the BCA summary, there is an opportunity to balance the simplicity of tabular information with creative graphical displays to present multiple dimensions of the analysis. The next section presents several options for displaying BCA results in tabular and graphical formats with various levels of supporting information.

Balance tabular information with graphical displays.

8.2 EXAMPLE SUMMARIES OF BCA RESULTS

There are numerous combinations and options to display and communicate BCA results. Regardless of the selected content and format, it is important to help decision-makers determine if a project alternative is worth the investment.

Figure 25 shows the "Results" sheet of the Highway Safety BCA Tool developed as a companion to this Guide. This is a blended display of tabular and graphical results, including the present value costs, present value benefits, net present value, and BCR. The upper right portion of the figure also presents the itemized present value benefits for each of the factors included in the analysis. The direct safety benefits relate to the change in crashes. The indirect safety benefits include the change in travel time, vehicle operating costs, emissions, and travel time reliability that result from a change in safety performance. The two charts within the figure present the same information graphically, providing a quick visual comparison of the various costs and benefits.

Case 1, Alternative 2

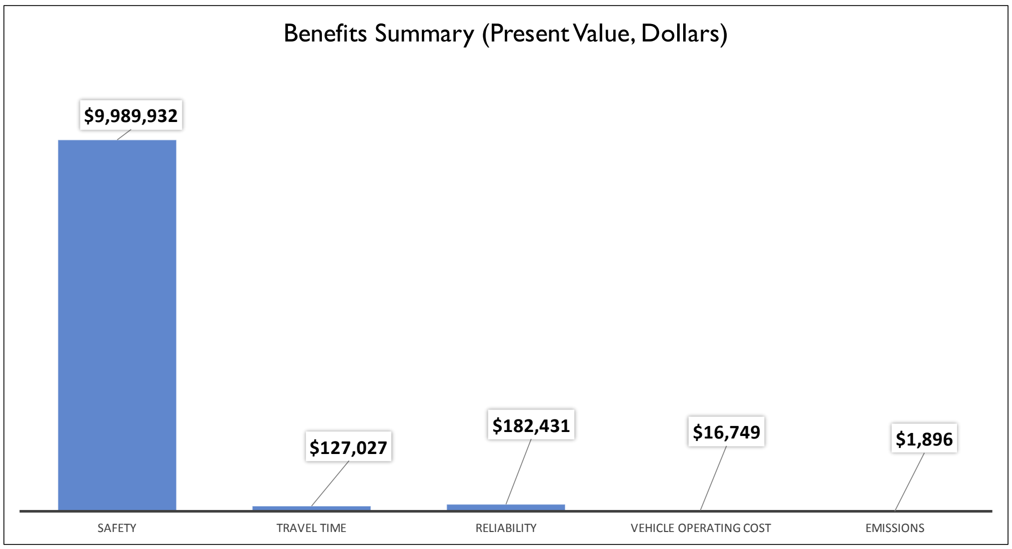
Benefit-Cost Analysis Summary Results

Print

AGENCY: DOT   **DATE** 2/14/2018

Present Value Costs ($ Dollars)	$900,000
Present Value Benefits ($ Dollar	$10,318,036
Net Present Value ($ Dollars)	$9,418,036
Benefit / Cost Ratio:	11.46
Discount Rate	3.0%

ITEMIZED BENEFITS ($ Dollars)	Present Value
Safety	$9,989,932
Travel Time	$127,027
Reliability	$182,431
Vehicle Operating Cost	$16,749
Emissions	$1,896
TOTAL BENEFITS	**$10,318,036**



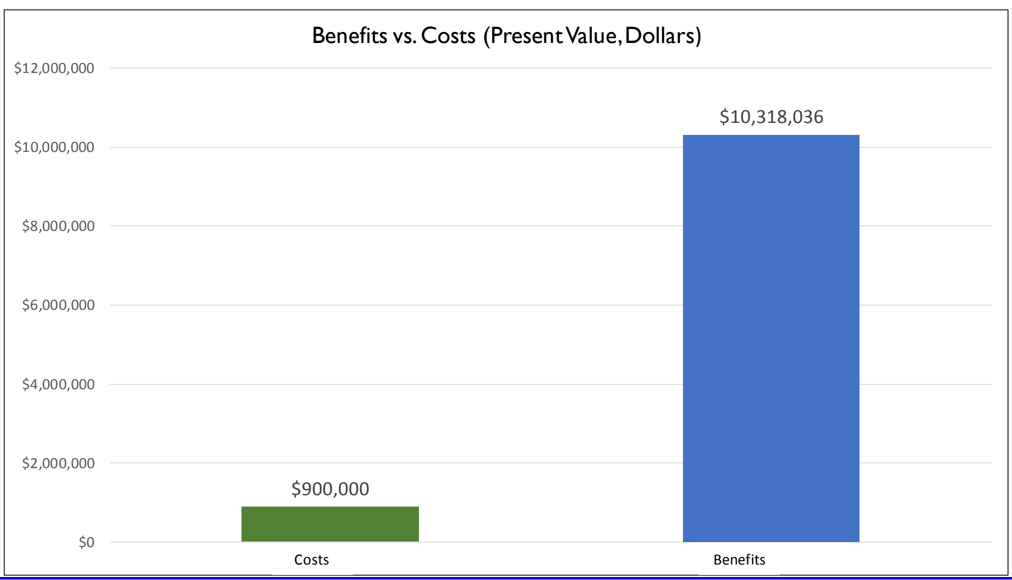


Figure 25. Chart. Tabular and graphical BCA results from Highway Safety BCA Tool.

Figure 26 and Figure 27 present examples of tabular displays of BCA results from the FHWA Tool for Operations Benefit-Cost Analysis (TOPS-BC) and the Clear Roads Cost-Benefit Analysis Toolkit, respectively.(37,38) Similar to the Highway Safety BCA Tool, the TOPS-BC tool presents the individual benefits for various categories such as travel time, travel time reliability, energy, and safety; however, these costs and benefits represent annual values rather than net present values. The Clear Roads tool includes a summary of the project parameters such as the analysis period, discount rate, and itemized costs. The Clear Roads tool also separates agency benefits, user (motorist) benefits, and society benefits.

Benefit/Cost Summary

		Generic Link Analysis	Signal Coordination: Central Control
Annual Benefits			
Travel Time	$	36,561	121,654
Travel Time Reliability	$	31,023	106,602
Energy	$	21,004	23,412
Safety	$	19,200	98,464
Other	$	0	0
User Entered	$	0	0
Total Annual Benefits	**$**	107,788	350,132
Annual Costs	**$**	62,521	166,580
Benefit/Cost Comparison			
Net Benefit	**$**	45,267	183,552
Benefit Cost Ratio		1.72	2.10

Figure 26. Chart. Tabular BCA results from TOPS-BC tool.(37)

Project Parameters

Analysis period (years):	10
Discount rate (%):	7
Material costs:	27000
Loaded labor cost per hour (shop rate):	21.42
Annual number of storm events:	20
Average labor hours per storm event per vehicle:	12
Number of equipped trucks:	900
Total trucks:	900
Total materials + labor for deicing:	4653720

Benefit Calculations

Agency Benefits	
Annualized	
Present Value	0
Annualized Benefit per Truck	0
User (Motorist) Benefits	
Annualized (click on field for calculator)	20941740
Present Value	147086018
Annualized Benefit per Truck	23269
Society Benefits	
Annualized	
Present Value	0
Annualized Benefit per Truck	0
Total Benefits	
Annualized	20941740
Present Value	147086018
Annualized Benefit per Truck	23269

Benefit-Cost Ratio

Agency Benefits	0
Total Benefits	15.5

Figure 27. Chart. Tabular BCA results from Clear Roads cost-benefit tool.[38]

This tabular output is often all that is needed by decision-makers; however, simple graphics can enhance communication, providing a visually-informative display of results. Simple graphics can aid in the understanding and interpretation of results, particularly for public officials and the public. It may be difficult for a non-technical audience to comprehend and compare numbers in a table, but a side-by-side graphical comparison, such as a bar chart, provides for much easier comparison. Several such graphic displays are discussed and displayed below.

Simple graphics can enhance communication of BCA results.

Figure 28 is one example of a simple graphical display from a Kansas City SCOUT program benefit-cost study. This graphic captures the essence of BCA, which is to provide a comparison of the benefits received from an expenditure of costs. It also conveys the relative importance of benefit and cost components to the overall benefit-cost ratio.

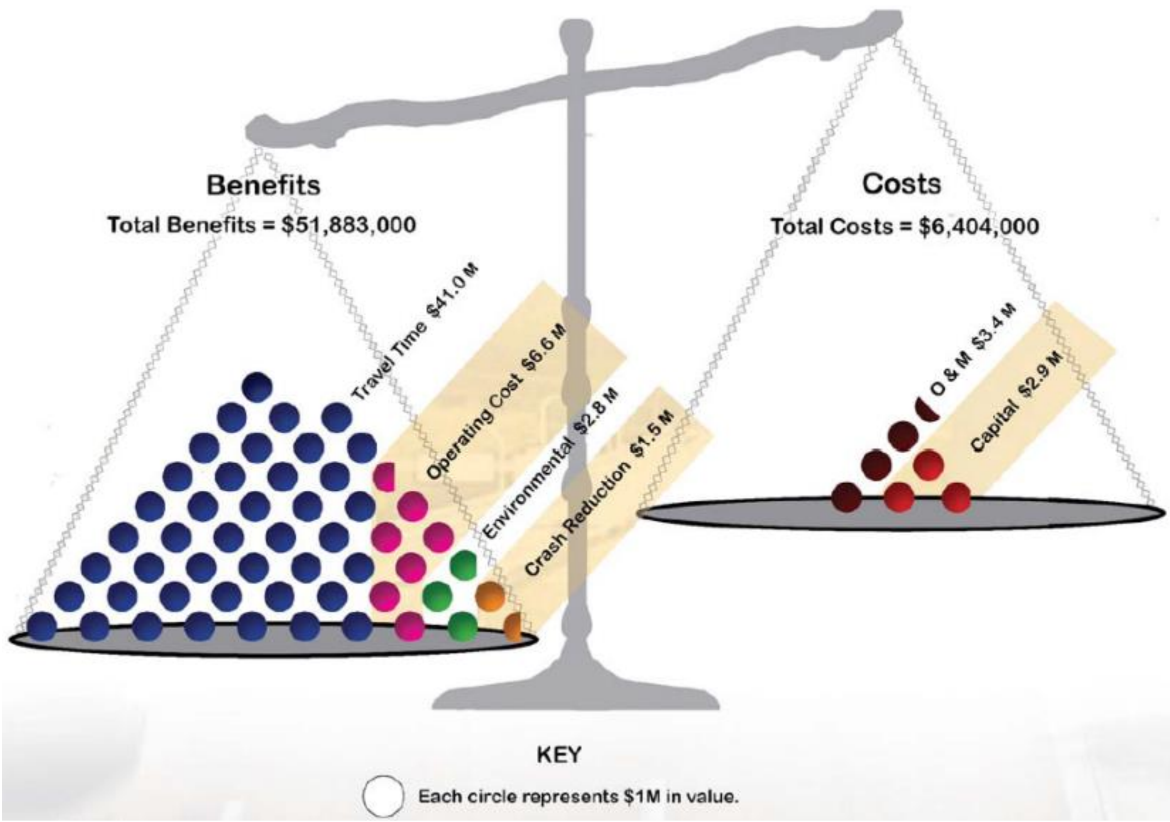
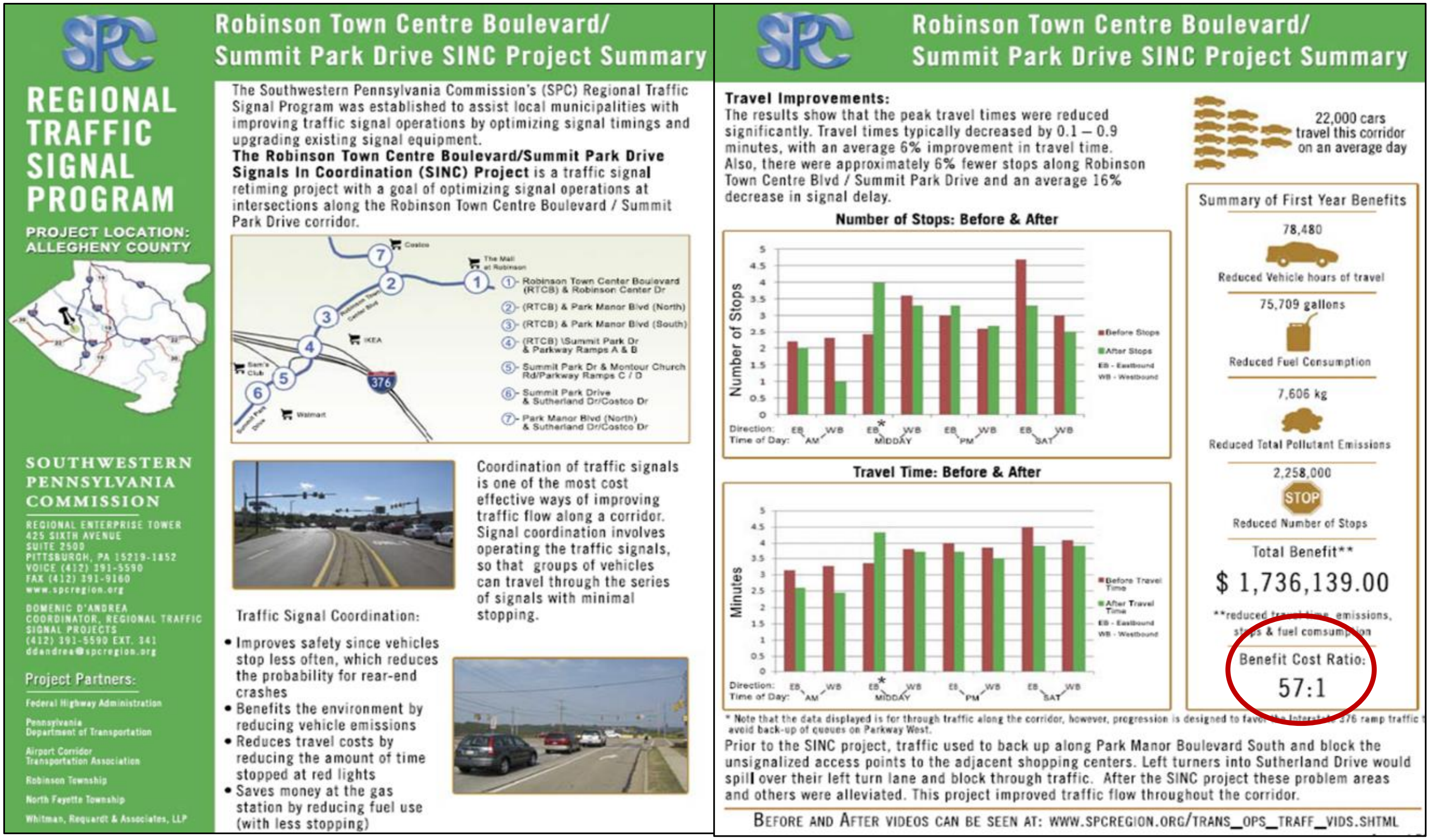


Figure 28. Chart. Graphical BCA results from Kansas City SCOUT.[39]

As another example, the Southwestern Pennsylvania Regional Traffic Signal Program used a “newsletter” approach to highlight the BCA results for a completed project. Figure 29 shows the format of this BCA display technique, which includes detailed information about the project., graphical displays of the first year of user benefits (number of stops and travel time), the dollar value of total benefits, and the BCR.



Robinson Town Centre Boulevard/ Summit Park Drive SINC Project Summary

REGIONAL TRAFFIC SIGNAL PROGRAM

PROJECT LOCATION: ALLEGHENY COUNTY

SOUTHWESTERN PENNSYLVANIA COMMISSION

REGIONAL ENTERPRISE TOWER
425 SIXTH AVENUE
SUITE 2500
PITTSBURGH, PA 15219-1852
VOICE (412) 391-5590
FAX (412) 391-9160
www.spcregion.org

DOMENIC D'ANDREA
COORDINATOR, REGIONAL TRAFFIC SIGNAL PROJECTS
(412) 391-5590 EXT. 341
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Project Partners:

Federal Highway Administration
Pennsylvania Department of Transportation
Airport Corridor Transportation Association
Robinson Township
North Fayette Township
Whitman, Requardt & Associates, LLP

The Southwestern Pennsylvania Commission's (SPC) Regional Traffic Signal Program was established to assist local municipalities with improving traffic signal operations by optimizing signal timings and upgrading existing signal equipment.

The Robinson Town Centre Boulevard/Summit Park Drive Signals In Coordination (SINC) Project is a traffic signal retiming project with a goal of optimizing signal operations at intersections along the Robinson Town Centre Boulevard / Summit Park Drive corridor.

Coordination of traffic signals is one of the most cost effective ways of improving traffic flow along a corridor. Signal coordination involves operating the traffic signals, so that groups of vehicles can travel through the series of signals with minimal stopping.

Traffic Signal Coordination:

- Improves safety since vehicles stop less often, which reduces the probability for rear-end crashes
- Benefits the environment by reducing vehicle emissions
- Reduces travel costs by reducing the amount of time stopped at red lights
- Saves money at the gas station by reducing fuel use (with less stopping)

Travel Improvements:
The results show that the peak travel times were reduced significantly. Travel times typically decreased by 0.1 – 0.9 minutes, with an average 6% improvement in travel time. Also, there were approximately 6% fewer stops along Robinson Town Centre Blvd / Summit Park Drive and an average 16% decrease in signal delay.

22,000 cars travel this corridor on an average day

Summary of First Year Benefits

78,480
Reduced Vehicle hours of travel

75,709 gallons
Reduced Fuel Consumption

7,606 kg
Reduced Total Pollutant Emissions

2,258,000
Reduced Number of Stops

Total Benefit**
$ 1,736,139.00

**reduced travel time, emissions, stops & fuel consumption

Benefit Cost Ratio:
57:1

* Note that the data displayed is for through traffic along the corridor, however, progression is designed to favor the Interstate 376 ramp traffic to avoid back-up of queues on Parkway West.

Prior to the SINC project, traffic used to back up along Park Manor Boulevard South and block the unsignalized access points to the adjacent shopping centers. Left turners into Sutherland Drive would spill over their left turn lane and block through traffic. After the SINC project these problem areas and others were alleviated. This project improved traffic flow throughout the corridor.

BEFORE AND AFTER VIDEOS CAN BE SEEN AT: WWW.SPCREGION.ORG/TRANS_OPS_TRAFF_VIDS.SHTML

Figure 29. Chart. Newsletter display of BCA results from Southwestern Pennsylvania Regional Signal Program.[9]

Finally, graphical displays can seek to present a large amount of information in a single display. The Metropolitan Transportation Commission (MTC) in the San Francisco Bay Area provided multimodal BCA evaluation results, displaying the magnitude of the BCA results for each of the various project performance measures concurrently (see Figure 30).

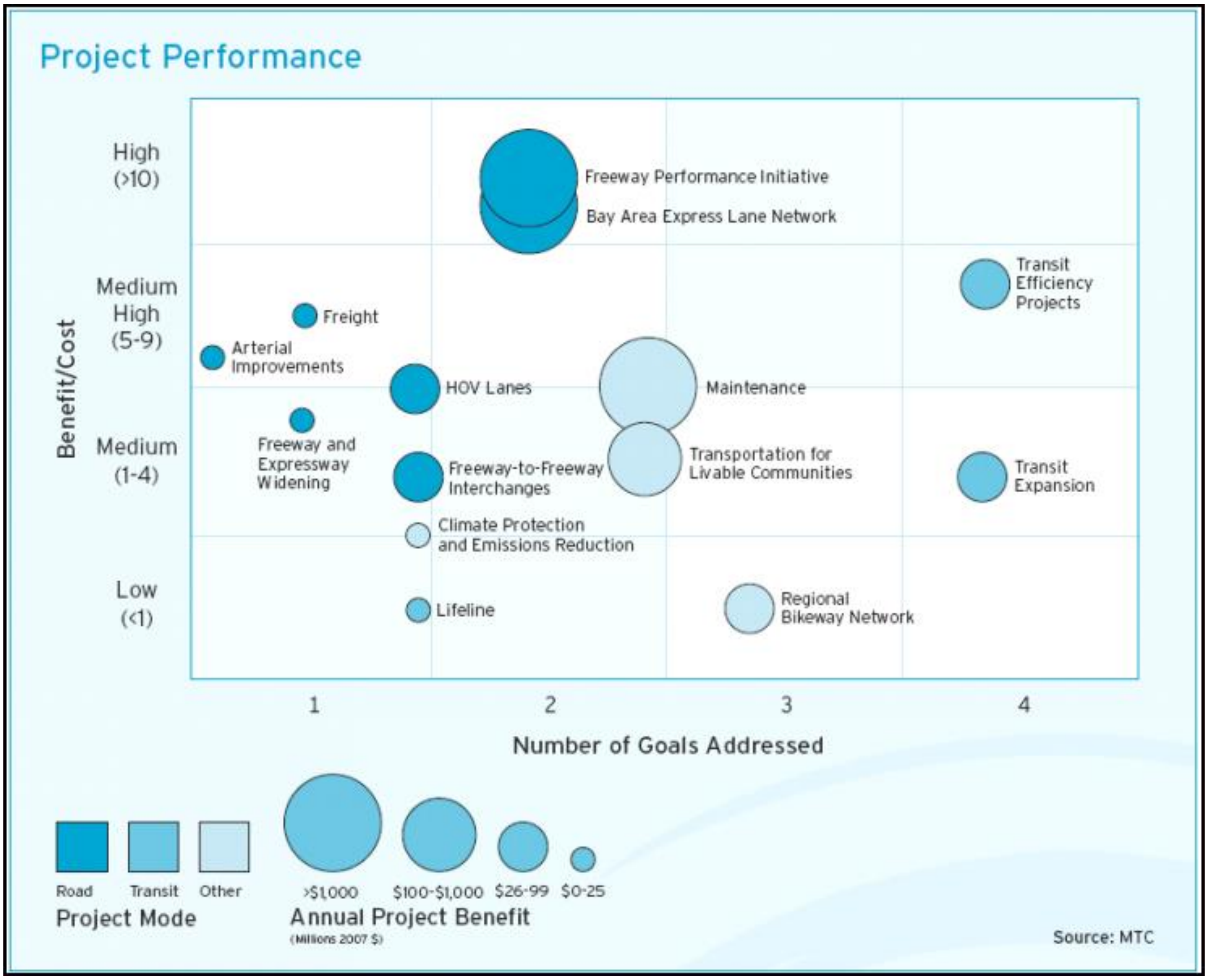

Figure 30. Chart. Multidimensional graphical BCA results from the Metropolitan Transportation Commission.[9]

In addition to communicating the BCA results to decision-makers, analysts can use tabular and graphical summaries as part of a sensitivity analysis. These displays can help the analyst to quickly compare the results among selected project assumptions. For example, Table 77 presents the results for the same alternative with two different assumptions for discount rate. The results are notably different under the two assumptions.

Analysts can use tabular and graphical summaries to support sensitivity analysis.

Table 77. BCA results for multiple sites example.

Benefit Category	3% Discount Rate	7% Discount Rate
Crash Benefits	$10,690,130	$7,327,701
Travel Time Benefits	$28,933	$19,832
Vehicle Operating Cost Benefits	$1,858	$1,274
Emissions Benefits	$239	$164
Travel Time Reliability Benefits	$33,098	$23,668
Present Value Benefits ($ Dollars)	**$10,754,258**	**$7,372,639**
Present Value Costs ($ Dollars)	**$620,356**	**$508,859**
Net Present Value ($ Dollars)	**$10,133,902**	**$6,863,780**
Benefit-Cost Ratio	**17.34**	**14.49**

8.3 CHAPTER SUMMARY

Chapter 8 presents several considerations and options for communicating BCA results to decision-makers and other potential audiences. The chapter begins with a discussion of several considerations for communicating results. It then presents several examples, illustrating tabular and graphical formats as well as different types of information that may be of interest in a summary report.

Key Takeaways from Chapter 8:

- The effort to conduct a BCA is unproductive unless decision-makers use the results to inform decisions.
- Balance tabular information with graphical displays.
- Simple graphics can enhance communication of BCA results.
- Analysts can use tabular and graphical summaries to support sensitivity analysis.

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9. SUMMARY

The purpose of this Guide is to assist transportation agencies in evaluating the economic effectiveness and efficiency of projects and programs in support of consistent and sound decision-making. This Guide introduces the BCA process and describes fundamental concepts and factors to consider when preparing for BCA. It also describes some of the more complex analytical concepts and the latest research to support more advanced BCA. Some of the more advanced topics covered in this Guide include quantifying the long-term safety performance of alternatives, estimating the safety impacts of multiple countermeasures, and capturing the derivative safety benefits such as changes in travel time, reliability, delay, and air emissions that result from fewer crashes.

The following are specific benefits to employing BCA in the roadway safety management and project development processes:

- **Documentation of Decision Process:** The discipline of quantifying and valuing the benefits and costs of highway projects also provides documentation to justify and explain the decision process to legislatures and the public.
- **Cost-Effective Design and Construction:** Economic analysis can inform agencies as to which of several project designs to implement at the lowest lifecycle cost to the agency, lowest work zone delay cost to the traveler, highest safety benefit to highway users, and the best affordable balance between these costs.
- **Best Return on Investment:** Economic analysis can help in planning, programming, and implementing transportation programs with the best rate of return for any given budget. It can also help to determine an optimal program budget.
- **Understanding Complex Projects:** In a time of growing public scrutiny of new and costly road projects, transportation agencies and other decision makers need to understand the comprehensive costs and benefits of these projects. A rigorous BCA can help to quantify and compare the impacts of project alternatives on safety, mobility, the environment, and regional economies.

A BCA attempts to capture all benefits to society from a project or course of action, and the cost to achieve those benefits, regardless of which party realizes the benefits and costs, or the form of these benefits and costs. A BCA should include project costs, user benefits, and non-user benefits (externalities) to identify the preferred alternative. Ideally, the level of effort that analysts allocate to quantifying benefits and costs in the BCA should be commensurate to the expense, complexity, and controversy of the project. Transportation professionals can use BCA to compare present value costs and benefits among alternatives. Used properly, BCA reveals the most economically-efficient investment alternative (i.e., the one that maximizes the net benefits to society relative to the allocation of resources).

A BCA differentiates costs and benefits by project costs (or agency costs), project benefits (or user benefits), and externalities (or non-user benefits). Project benefits and externalities include costs avoided, but also include negative benefits (disbenefits) such as increased crashes or air emissions. Analysts monetize project benefits by assigning dollar values to the different effects.

Project costs should include an accounting of all public-sector and private-sector costs, when applicable. These costs represent:

- Initial capital costs of implementing the project, including planning, design, construction/installation, and equipment costs.
- Continuing operations and maintenance costs necessary to keep the project operational, including items such as power, communications, labor, and routine maintenance (excludes replacement costs).
- Replacement cost of equipment that reaches the end of its useful life during the time horizon of the analysis.
- "End of Project" costs necessary to close temporary projects or any residual or salvage value of equipment at the end of the time horizon of the analysis.

Project benefits include reductions in crash frequency and severity, travel time and delay, and vehicle operating costs. Externalities (or non-user benefits) include reductions in air emissions, noise, and impacts to natural habitat and wetlands. These benefits and externalities may be a direct benefit from the project or a residual benefit from a reduction in crashes.

Measuring the benefits of a safety project first requires estimates for the measures in the base condition (e.g., the do-nothing alternative). The BCA estimates project benefits by calculating changes between the base condition and project alternative(s). Where possible, the analyst should estimate the safety benefits based on predicted or expected crash frequency rather than observed crash frequency. A BCA uses the following measures to quantify project benefits and disbenefits:

- Safety (frequency and severity of crashes).
- Mobility (travel time).
- Reliability (total delay).
- Vehicle operating cost (fuel and nonfuel use costs).
- Environment (emissions).

In BCA, the transportation professional applies a discount rate to the future annual benefits and costs. The discount rate is the rate at which predicted cash expenditures (costs) or inflows (benefits) decline in future years to reflect the time value of money. Once the analyst has converted all benefits and costs to present values, there are several measures analysts can use to compare alternatives in a BCA:

- **Benefit-cost ratio (BCR):** The BCR is the ratio of present value benefits (including negative benefits) to present value costs (initial and continuing costs over the project lifecycle). In this context, the BCR is the same as the rate of return and return on investment. A BCR greater than 1.0 indicates that benefits exceed costs, and the project is economically justified. In general, a higher BCR is desirable. The BCR is most appropriate for prioritizing project alternatives when funding restrictions apply (e.g., prioritizing locations or alternatives within a project with a fixed budget).
- **Net present value (NPV):** The NPV is the difference between present value benefits and present value costs. NPV is also referred to as net benefits or net present worth. If the NPV is greater than 0.0, then the benefits exceed the costs, and the project is economically justified. In general, a higher NPV is desirable. An agency can use NPV to determine the alternative with the highest net benefits for a given project.
- **Cost-effectiveness index (CEI):** The CEI is the average cost of a project to reduce one crash. The CEI is calculated by dividing the present value cost (PVC) by the expected crashes reduced over the service life of the project. In general, a low CEI is desirable. The CEI is typically based on total crashes, but can be expressed in terms of a specific crash type or severity level (e.g., cost to reduce one fatal and serious injury crash). The CEI does not account for the magnitude of monetary benefits. As such, it is not an appropriate measure to justify projects economically. It can, however, serve as a measure when it is difficult to monetize benefits (e.g., the cost per new transit rider).

USDOT recommends analysts use the NPV or BCR for most economic evaluations. Both measures used in combination, as well as standalone present value costs and benefits, will provide better information to agencies. If benefits exceed costs, the NPV is positive and the BCR is greater than 1.0, indicating the project is potentially economically justifiable. Where two or more alternatives for a project exist, the one with the highest NPV over an equivalent analysis period provides the most net benefits. Within a budget, maximizing BCR among countermeasures or locations within a project provides the greatest economic efficiency. Policy considerations, perceived risk, funding availability, and other influences may also affect the selection of an alternative. Analysts may use other available BCA measures depending on the technical problem or the agency policy or preference.

In summary, BCA is critical to understanding the potential return on investment from potential projects. Highway safety BCA allows State and local agencies to quantify and assess safety impacts alongside other decision factors such as operational efficiency, environmental impacts, and pavement preservation. While BCA is a policy or procedure decision, this Guide and related spreadsheet tool will assist agencies in justifying the need to perform BCA, identifying appropriate inputs and parameters for analysis, and conducting sound highway safety BCA to evaluate the economic effectiveness and efficiency of projects. A reliable BCA will help to inform decisions and improve investments.

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APPENDIX A: GLOSSARY OF TERMS

Term	Definition
Benefit-Cost Analysis	A systematic process for calculating and comparing benefits and costs of a project.
Benefit/Cost Ratio	Measure calculated by dividing the incremental monetized benefits related to a project by the incremental costs of that project. May either be expressed as a ratio (2:1) or a resultant value (2). B/C ratios greater than one indicate that a project is efficient (benefits exceed costs). B/C ratios less than one indicate that a project is inefficient (costs exceed benefits).
Countermeasure	Roadway-based strategy intended to reduce the crash frequency or severity, or both at a site.
Crash Modification Factor	Multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure.
Crash Reduction Factor	The percentage crash reduction that might be expected after implementing a given countermeasure.
Direct Benefits	Those measurable benefits that may be directly attributed to the project investment.
Discount Rate	The rate at which predicted cash expenditures (costs) or inflows (benefits) are reduced in future years to reflect the time cost of money. The purpose of the discount rate is to convert future values to present value.
Efficient	Projects determined to have benefits greater than their costs and are economically justifiable (B/C ratio greater than one).
Externality	The uncompensated impact of one person's actions on the well-being of a bystander. In the case of transportation investments, "bystanders" are the nonusers of the project. When the impact benefits the nonuser, this is called a positive externality. When the impact is adverse, this is called a negative externality.
Inefficient	Projects determined to have benefits less than their costs and are economically unjustifiable (B/C ratio less than one).
Life-Cycle Costs	All costs accruing to highway agencies and to users of the highway system as a result of agency construction and maintenance activities. These costs include initial construction, maintenance, rehabilitation and end-of-life

Term	Definition
	costs, as well as user costs such as vehicle operating, travel time and crash costs associated with work zones.
Measure of Effectiveness	Metric used to evaluate the level of impact of a project.
Net Benefit	The sum of a project benefits minus the sum of the project costs.
Net Present Value	The sum of the discounted stream of expected benefits and costs over a selected time horizon.
Operations and Maintenance Costs	The continuing costs necessary to keep the project performing as planned, including items, such as power, communications, labor, and routine maintenance.
Replacement Costs	The cost of replacing equipment that reaches the end of its useful life during the time horizon of the analysis.
Safety Performance Function	An equation used to predict the average number of crashes per year at a location as a function of exposure and, in some cases, roadway or intersection characteristics.
Time Cost of Money	The impact of time on the value of future benefits and costs. Money spent or earned today is more valuable than the same amount of money promised in a future year since the money earned today can be invested and earn additional revenue in the interim years. Therefore, benefits and costs accruing in later years of an analysis are often valued at a discounted rate.
Value of a Statistical Life	Additional cost that individuals would be willing to bear for improvements in safety (that is, reductions in risks) that, in the aggregate, reduce the expected number of fatalities by one.

For More Information:

Visit https://safety.fhwa.dot.gov/

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