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Integration of Safety in the Project Development Process and Beyond: A Context Sensitive Approach

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FOREWORD

There are many challenges to successfully completing projects, particularly those in urban areas with multiple modes of transportation, where space is limited, and where stakeholder desires are many and varied. Transportation project development is now widely understood to involve the weighing of tradeoffs between cost (both initial and life cycle), user mobility, socioeconomic and environmental effects (for example, air and noise quality, wetlands, cultural resources, visual effects, and environmental justice communities), rights-of-way, adjacent land use, and safety. Project development includes consideration of context and the community and environment in which a project may be developed.

For any project, a multitude of solutions may be possible, each with its own unique set of costs and benefits. The relative importance of all identified costs and benefits can vary widely according to the community values, context, and project specifics. Implementing such a process and making a good decision among the choices require full knowledge of the quantitative and qualitative effects of the many identified values and issues, including safety. Project concepts born through a transparent process that is based on quantitative and objective information can be considered engineered solutions. Among those, a true "best value" solution can be identified only if decision making reflects sound science and project-specific values.

With respect to safety considerations in project development, the default assessment has historically been by whether a roadway, design alternative, or design element meets minimum accepted design practices, standards, and/or warrants (nominal safety) rather than by substantive safety, which defines safety in terms of actual (or expected) performance as defined by the frequency and severity of crashes. The American Association of State Highway and Transportation Officials' *Highway Safety Manual* (HSM)[1] and other publications now offer transportation professionals many tools to assess the effects of their design choices on safety performance. Such publications are filling the gap in knowledge associated with geometric design and traffic operational effects on safety performance. A logical next step in the evolution of the context sensitive solution (CSS) process is the identification of resources and tools to be used by the transportation profession for best integrating safety into the project development process.

By quantifying the safety implications and by applying context sensitive and flexible design principles, the highway designer, safety engineer, planning team, and general public can make the best possible decisions for their community.

This report builds on work related to the recommended practice, *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach,* by the Institute of Transportation Engineers, the Federal Highway Administration, and Congress for the New Urbanism and to the dialog that was initiated with the ITE members in support of implementing the CSS. This report focuses on the consideration of safety in the project development process and its relationship to highway design elements.

This report presents the methodology to integrate substantive safety into the project development process. The process of incorporating safety into design begins with an examination of how an agency fundamentally thinks about safety and a recognition that new approaches for analyzing safety must be adopted as part of an agency's policies and procedures. Best practices are presented for the various stages of project development, including planning, engineering and design, construction, operations, and system preservation and maintenance. Case studies and project examples have been included to illustrate how the concepts can be tailored to project size, scope, and context.

[1] *American Association of State Highway and Transportation Officials.* Highway Safety Manual*, 1st ed. Washington, DC: AASHTO, 2010.*

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ABBREVIATIONS AND ACRONYMS

3Rs	resurfacing, restoration, rehabilitation
AASHTO	American Association of State Highway and Transportation Officials
ADOT	Arizona Department of Transportation
CDOT	Chicago Department of Transportation
CFR	*Code of Federal Regulations*
CMF	crash modification factor
CSD	context sensitive design
CSS	context sensitive solution
DOT	Department of Transportation
EIS	Environmental Impact Statement
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GIS	geographic information system
HOV	high-occupancy vehicle
HSIP	Highway Safety Improvement Program
HSM	*Highway Safety Manual*
IHSDM	Interactive Highway Safety Design Model
ISATe	Interchange Safety Analysis Tool–Enhanced
ITE	Institute of Transportation Engineers
ITS	intelligent transportation system
KDOT	Kansas Department of Transportation
LADOTD	Louisiana Department of Transportation and Development
LOS	level of service
LRTP	long-range transportation plan
LTAP	Local Technical Assistance Program
MAS	Motorist Awareness System
MDT	Montana Department of Transportation
MMIRE	Model Minimum Inventory of Roadway Elements
MMUCC	Model Minimum Uniform Crash Criteria
MoDOT	Missouri Department of Transportation
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
NHI	National Highway Institute
NYCDOT	New York City Department of Transportation
ODOT	Ohio Department of Transportation
PBCAT	Pedestrian and Bicycle Crash Analysis Tool
PDP	project development process
PSI	potential for safety improvement
RSA	road safety audit
RSAP	Roadside Safety Analysis Program
RSAR	road safety audit review
SDOT	Seattle Department of Transportation
SHSP	Strategic Highway Safety Plan
SLU	South Lake Union (Seattle)
SPF	safety performance function
SP&M	system preservation and maintenance
SR	State Route
SSAM	Surrogate Safety Assessment Model
STIP	Statewide Transportation Improvement Program
TIB	Washington State Transportation Improvement Board
TIP	transportation improvement program
TMP	Traffic Management Plan
TRB	Transportation Research Board
TSM&O	transportation system management and operations
TSP	Transportation Safety Planning Working Group
U.S.C.	United States Code
USDOT	U.S. Department of Transportation
usRAP	U.S. Road Assessment Program
VE	value engineering
VSL	variable speed limits

INTRODUCTION

1

Photo courtesy of Thinkstock.

1.1 PURPOSE OF THIS REPORT

This report provides information and background to transportation agencies and professionals so that they can apply the most appropriate technical knowledge about quantitative safety performance—crashes, their outcomes, and causual factors—to develop projects for a range of highway and street types and contexts. With such input, professionals can compare and contrast safety data with other measureable data about the environment, costs, traffic operations, and other factors, and they can make fully informed decisions.

This report conveys a common understanding of and approach to how substantive safety, or performance-based safety, should be integrated into project development and throughout the project life cycle. The following chapters demonstrate how to integrate performance-based safety using best practices in quantitative methods and tools into the many stages of project development and operation of the facility. The best practices incorporate basic technical knowledge on safety effects, as well as analysis processes tailored to project size, scope, and context. Readers will learn to determine and estimate meaningful measures of safety performance on the basis of a project's contextual, geometric, and traffic operational attributes. They will also learn how to interpret safety performance measures and to incorporate them in their decision-making processes.

1.2 BACKGROUND

The default measure of safety performance is often nominal safety rather than substantive safety. *Nominal safety* is the evaluation of safety by determining whether a roadway, design alternative, or design element meets minimum design standards or warrants. *Substantive safety,* however, evaluates safety in terms of actual (or expected) performance as measured by frequency and severity of crashes.

There is limited value in using nominal safety as the *sole* determinant of safety performance. Design standards and warrants are often intentionally broad and by nature focus on

standardizing the approach to design or design elements for consistency. A nominal safety approach will not necessarily consider the context in which the standards and warrants are to be applied. Many standards were developed without fully understanding the relationships that the design elements—or, more important, changes in design elements—have to safety performance. However, that concept of context sensitivity is an inherent part of substantive safety, in that an evaluation of substantive safety must consider how and where the design is being applied and must appreciate the incremental effects that variations in those conditions have on safety performance. Without consideration of substantive safety, in the case where more than one "nominally safe" solution is possible, professionals are faced with many questions that may have no clear answers:

- How do we balance safety against other community, environmental, economic, or mobility values?
- How do we determine what compromises are reasonable and whether it is possible to trade safety against them?
- How do we know if the owning agency is at risk for making such tradeoffs?
- How can one select the preferred solution?

The quantification of substantive safety puts it on a par with the other evaluation criteria, such as environmental impacts, community values, right-of-way, mobility, and congestion, and thus provides the means by which professionals may make informed project decisions and answer those questions. This report demonstrates how those types of questions can be answered to the satisfaction of stakeholders for any project by integrating substantive safety into design decisions.

1.2.1 Context Sensitivity, Flexibility in Design, and Practical Design

In recent years, the development of surface transportation projects has evolved to reflect many of the core principles of context sensitive solutions (CSS). Project development is now widely understood to involve the weighing and balancing of tradeoffs among cost (both initial and life cycle), user mobility, socioeconomic and environmental effects, rights-of-way, adjacent land use, *and safety*. For any project, numerous solutions may be possible, each with unique costs and benefits. The relative importance of the costs and benefits can vary widely according to community values, context, and project specifics. Engineering judgment must be applied when developing designs for roadway improvement projects. Successful projects involve a transparent and consensus-based decision process that outlines what is important and how it will be measured or estimated. Implementing such a process and making a good decision requires full knowledge of the quantitative and qualitative effects of the many identified values and issues, including safety.

The Federal Highway Administration defines context sensitive solutions (CSS) as "a collaborative, interdisciplinary approach that involves all stakeholders in providing a transportation facility that fits its setting. It is an approach that leads to preserving and enhancing scenic, aesthetic, historic, community, and environmental resources, while improving or maintaining safety, mobility, and infrastructure conditions."

The American Association of State Highway and Transportation Officials' (AASHTO's) guidance about providing for flexibility in design encourages agencies to incorporate the objectives of CSS principles such as substantive safety performance into project development. Flexibility in design (as discussed in AASHTO's *A Guide for Achieving Flexibility in Highway Design* and the Federal Highway Administration's [FHWA's] *Flexibility in Highway Design*[1]) helps agencies deliver solutions that balance safety and mobility for all users with the preservation and enhancement of community and environmental resources. That concept of "flexibility in design" is encouraged through use of an open, collaborative, and creative thinking process by which flexibility is exercised in (a) design approach, (b) use of standards and criteria, (c) implementation of solutions, and (d) consideration of the context of the area in which the project is being implemented, such as improvements to the street side or multimodal considerations that provide integration of land use, transportation, and infrastructure needs.

Many agencies, faced with growing needs and limited funds, are taking the concepts of flexibility in design and CSS a step further through applications of a concept called practical design. *Flexibility in design helps agencies deliver solutions that balance safety and mobility for all users with the preservation and enhancement of community and environmental resources. Agencies that adopt the practical design philosophy will continue to analyze project development decisions and tradeoffs but will emphasize the need to use quantitative performance information to support decision making.*[2]

1.2.2 Role of Substantive Safety in Project Development

FHWA and AASHTO have made many investments in recent years to advance the knowledge base and science of highway safety. Many agencies have begun to provide high-level policy guidance and direction in implementing substantive safety principles into project development, but such direction has been slow to filter down to middle management, including the safety and design engineer who must implement project-level decisions daily. As a result, until only recently, quantitative approaches to safety have been the missing piece in project development. Objective measures have not typically been used. Adherence or reference to standards has been used to evaluate safety, and so perceptions and opinions

have informed decision making rather than using quantitative facts on actual safety performance. As a result, safety may have been undervalued in the selection of alternatives when compared with competing values.

AASHTO's *Highway Safety Manual*[3] and other publications offer transportation professionals many resources and tools for assessing the effects of their decisions on safety performance. Such publications are adding to the knowledge associated with geometric design and traffic operational effects on safety performance. By understanding the safety implications associated with transportation facility planning and design, the highway designer, safety engineer, planning team, and general public can make the best possible decisions for their community.

1.3 REPORT OBJECTIVES

This report has the following objectives:

- Help technical professionals understand nominal safety versus substantive safety and how the latter enables adoption of a performance-based design approach throughout the project development process (PDP).
- Provide guidance to integrate safety into project development decisions, and demonstrate how balancing safety measures with community, environmental, economic, and mobility measures is not only possible but also appropriate in project development.
- Demonstrate what the relationship is between substantive safety and nominal safety in typical project applications and how those two aspects of safety can be integrated into the PDP.
- Provide a better understanding of the role of engineering judgment in the consideration of nominal and substantive safety in the PDP.
- Assemble and synthesize the safety knowledge base and tools in the transportation industry, so they may be readily applied to project development.
- Provide information that will help planners, designers, and other stakeholders incorporate safety quantitatively with the appropriate flexibility in design when considering the context of the surrounding community.
- Describe the link between quantitative safety and CSS; transportation solutions must be safe, feasible, and sensitive to context in order to be harmonious with the community and its values.
- Explain how tort liability and risk management implicate the integration of safety.

1.4 RELATIONSHIP OF THIS REPORT TO OTHER DOCUMENTS

This report supplements and expands on policies, guides, and standards commonly used by State and local transportation, engineering, and public works engineers and planners. It is intended to build on previous and ongoing work related to the Institute of Transportation Engineers' *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach*.[4] The report focuses on integrating safety into the PDP within the context of CSS from a quantitative, substantive, analytical, and technical perspective.

Other documents available to assist in integrating substantive safety into project development are AASHTO's *Highway Safety Manual* as a source for analytical tools and methods that can be used for planning, evaluation, and implementation of CSS; the *Highway Safety Improvement Program Manual*[5] published by FHWA as a reference for incorporating safety into safety-funded projects, as well as other types of projects; and FHWA's *Integrating Road Safety into NEPA Analysis: A Practitioner's Primer*,[6] which presents basic concepts for including meaningful analysis of project safety issues in environmental analysis.

The National Cooperative Highway Research Program (NCHRP) *Report 500* series[7] of guides can also assist State and local agencies in reducing injuries and fatalities resulting from traffic crashes in the 23 emphasis areas outlined in AASHTO's *Strategic Highway Safety Plan*.[8] The *Transportation Planner's Safety Desk Reference*,[9] prepared by the Transportation Safety Planning Working Group with support from FHWA, provides strategies in 17 emphasis areas that may be implemented by transportation planners.

This publication expands on information published in *NCHRP Report 480: A Guide to Best Practices for Achieving Context Sensitive Solutions*[10] and the *Manual on Uniform Traffic Control Devices*[11] and builds on the considerations in developing context sensitive solutions described in *A Guide for Achieving Flexibility in Highway Design*.[12]

1.5 REPORT ORGANIZATION

Throughout this report, information is presented about the best means by which to consider safety as a part of project development decisions and to demonstrate how balancing safety with community, environmental, economic, and mobility measures is not only possible but also appropriate. Readers will gain an appreciation of the importance of and need for understanding quantitative safety performance to shape how projects develop and how tradeoff decisions are made. It will become clear that safety is no different from other key considerations, in that it can and should be quantified, must be evaluated, and can in fact be weighed against other stakeholder values without posing risk to decision making.

This report contains the following chapters:

- Chapter 2, "Safety in the Project Development Process," provides an overview of the PDP, including where safety considerations should be included and addressed throughout the process.

- Chapter 3, "Organizational Needs for Integration of Safety in the Project Development Process," presents organizational considerations related to the integration of safety into the PDP.
- Chapter 4, "Planning and Programming"; chapter 5, "Engineering and Design"; chapter 6, "Work Zone Safety"; chapter 7, "Transportation System Management and Operations"; and chapter 8, "System Preservation and Maintenance," focus on the opportunities for integrating and applying substantive safety principles, resources, and tools to the various stages of the PDP.
- Chapter 9, "Tort Liability and Risk Management," discusses the tort liability implications of integrating substantive safety into project development and presents various best practices for risk management.
- Chapter 10, "Case Studies," presents 12 case studies from across the United States.

1.6 INTENDED AUDIENCE

This report is intended to be useful and relevant to a broad audience, including the following:

- Practitioners who are involved with any aspect of project development;
- Project managers who direct multidisciplinary teams and interact with external stakeholders;
- Transportation planners, traffic engineers, and highway designers who are involved with concept planning, alternatives development, preliminary engineering, and design;
- Traffic safety database managers who maintain and provide crash data and analyses;
- Senior managers who are part of transportation agencies and who are responsible for setting priorities, managing resources, and making major project decisions;
- Agency risk managers, legal staff members, public involvement specialists, and communications representatives who are responsible for explaining and defending agency actions to their sponsors and the public; and
- Stakeholders who are interested in the safety performance of roadways and streets.
- Those responsible for preserving and maintaining the system's operations and sustainability.

1.7 REFERENCES

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2. Federal Highway Administration, "Brief: Overview of Performance-Based Practical Design (PBPD)," 2014, http://www.fhwa.dot.gov/design/pbpd/documents/pbpd_brief.cfm.
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4. Institute of Transportation Engineers, *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach* (Washington, DC: ITE, 2010).
5. Federal Highway Administration, *Highway Safety Improvement Program Manual* (Washington, DC: FHWA, 2010).
6. Federal Highway Administration, *Integrating Road Safety into NEPA Analysis: A Practitioner's Primer* (Washington, DC: FHWA, 2011).
7. National Cooperative Highway Research Program, *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan*, vols. 1–23 (Washington, DC: Transportation Research Board, 2003–2009).
8. American Association of State Highway and Transportation Officials, *Strategic Highway Safety Plan* (Washington, DC: AASHTO, 2005).
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10. National Cooperative Highway Research Program, *NCHRP Report 480: A Guide to Best Practices for Achieving Context Sensitive Solutions* (Washington, DC: Transportation Research Board, 2002).
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12. AASHTO, *A Guide for Achieving Flexibility in Highway Design.*

SAFETY IN THE PROJECT DEVELOPMENT PROCESS

2

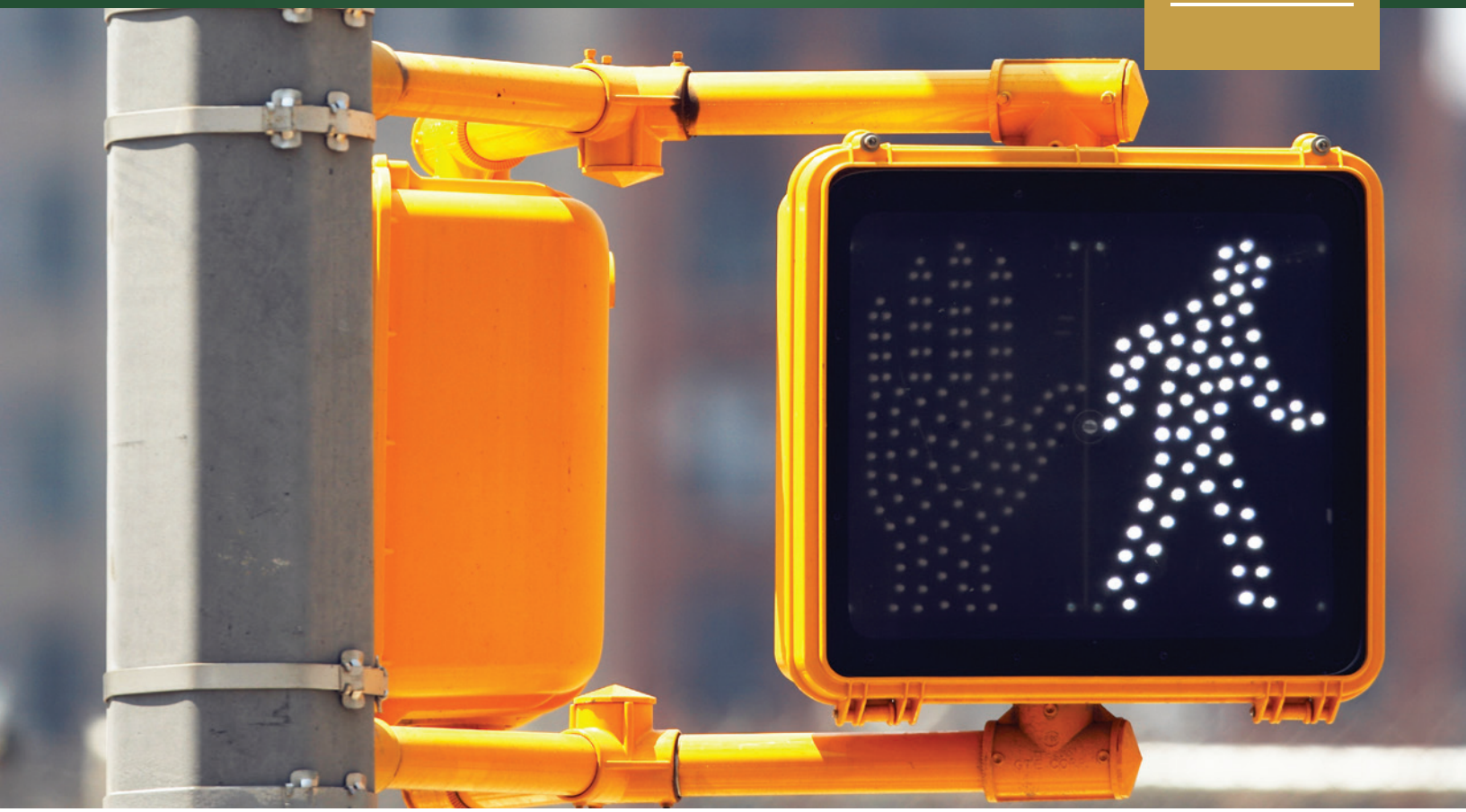


Photo courtesy of Thinkstock.

2.1 INTRODUCTION

Project development can be complex and can involve interdisciplinary tasks that are structured to address multiple stakeholder concerns in a context sensitive process. Project development includes many steps, and the subject of safety should be considered in each. This chapter introduces a framework within which safety can be *objectively* considered, thereby enabling the professional staff, which is working with stakeholders, to address safety issues in meaningful terms that can be tailored to the project's context.

This chapter provides an overview of the project development process (PDP), including where safety considerations should be included and addressed throughout the process. A highlight of this chapter is a discussion of the two dimensions of safety: nominal and substantive. For many transportation professionals, that discussion will offer new insights into ways to address safety issues in meaningful terms for project development and ways to show how and where both dimensions of safety are applied within the project development framework. Ultimately, those concepts will help transportation professionals better understand and deliver "performance-based" solutions.

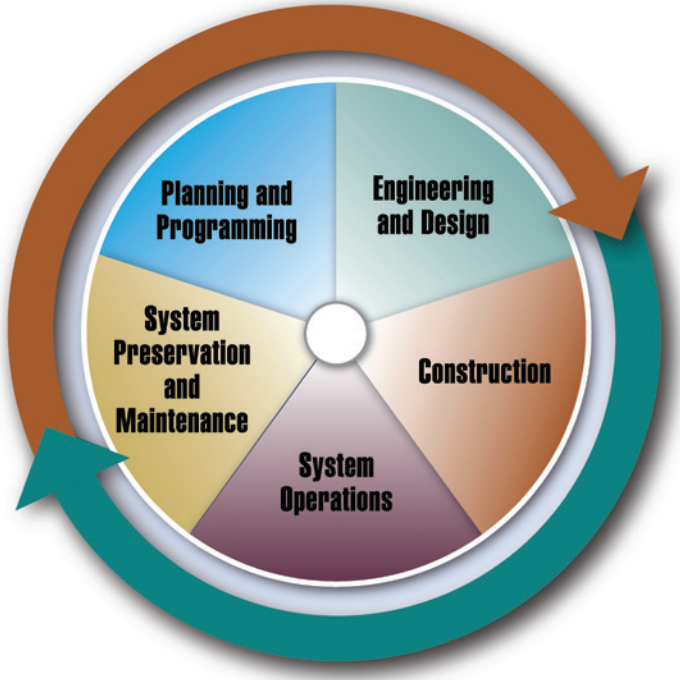
This chapter has the following objectives:

- Describe the PDP, including an overview of the various phases of project development.
- Provide the latest information about the best means to consider safety in project decision making.
- Discuss nominal safety and substantive safety, which are the two dimensions of safety.
- Demonstrate the roles for both dimensions of safety within project development.

2.2 OVERVIEW OF THE PROJECT DEVELOPMENT PROCESS

The PDP guides a transportation project through a series of steps spanning the project's life cycle, from development of initial ideas to implementation of solutions in order to accomplish a specified

Figure 2-1. Development of Transportation Projects



Source: CH2M HILL.

set of goals and objectives. The project development process considers all current and future users of a transportation facility. The specific components of that process will vary by agency, but they will typically include tasks such as assembling stakeholders; defining needs; identifying constraints and issues; establishing project objectives and evaluation criteria; developing and evaluating multiple alternatives; selecting a preferred alternative, preliminary, and final design; and implementing the solution.

Before the recent advances in the science of safety, transportation professionals and other stakeholders did not have the tools to meaningfully incorporate safety into the PDP. Too often, the topic was addressed in only abstract or subjective terms. Science-based knowledge had been limited, and myths and misperceptions developed regarding what constituted desirable or acceptable "safe" solutions. More important, the transportation planning and design approaches to incorporating safety lacked the capability to differentiate among potential solutions, any of which may have been reasonable given other transportation and stakeholder values and costs.

Project development begins with the stated priorities of an agency or owner, thereby reflecting context, resources and constraints, and values. Priorities dictate multiyear programs (long-range plans, capital improvement plans, transportation improvement programs, and others). Specific projects are identified according to an understood transportation need (infrastructure condition, mobility, safety, or some combination thereof). Project limits, scope, and development process are defined according to the specific transportation needs. Issues common to all projects, regardless of purpose and need, include costs, right-of-way or spatial footprint, traffic operational quality or mobility, environmental effects and issues, and safety. As such, projects require a range of technical expertise in working in an interdisciplinary environment. Safety is among those areas.

As an agency identifies a need and initiates development of a solution, its PDP is engaged. Figure 2-1 shows a typical PDP. In the planning and programming phase, agencies assess their existing conditions, establish purpose and need, identify future travel demands, develop alternatives using project-specific performance measures, and determine the preferred alternative. In the engineering and design phase, agencies develop preliminary and final design plans and evaluate the effect of applying project-specific performance measures in design changes. The final design alternative is built during the construction phase. During the system operations phase, agencies monitor existing operations to maintain optimal conditions on the facility. Finally, asset management and maintenance activities are regularly programmed to sustain a desired state of good repair over the life cycle of the facility at a minimum practicable cost.

The basic project development actions are planning and programming, engineering and design, construction, system operations, and asset management and maintenance. Performance monitoring, evaluation, and continuous process improvement are the factors (arrow) that bind the steps into a continuous process capable of evolving to meet the ever-changing transportation needs of roadway systems. When followed, the process ensures that the critical success factors in project development can be met.

Note that the steps are intentionally broad and are presented here to introduce the basic elements of the PDP and to guide discussion in this document. Each step within the process and how substantive safety can be incorporated into that step will be discussed in detail in subsequent chapters.

2.3 CONCEPTS AND PRINCIPLES RELATED TO THE INTEGRATION OF SAFETY INTO THE PROJECT DEVELOPMENT PROCESS

2.3.1 Two Dimensions of Safety: Nominal and Substantive Safety

With respect to safety considerations in project development, the default assessment has historically been made by whether a roadway, design alternative, or design element meets minimum accepted design practices, standards, and/or warrants (nominal safety) rather than by substantive safety, which defines safety in terms of actual (or expected) performance as defined by the frequency and severity of crashes. Although the American Association of State Highway and Transportation Officials (AASHTO) has reinforced the importance of applying design criteria and standards as a fundamental aspect of project development, it also acknowledges that the application of standards requires flexibility and encourages full use of the

flexibility in design that is currently available within the limits of the standards, policies, and procedures.[1] Transportation facility designers are encouraged to apply that flexibility in achieving a balanced road design and to resolve design issues. When seeking flexibility in developing projects, defining project-specific design criteria—or pursuing design exceptions on projects that may not meet standard AASHTO, State, or local criteria—an understanding of the quantitative safety differences of design variables allows the practitioner to make sound engineering judgments with regard to incorporating safety into project development.

The direct application of established design criteria or standards (i.e., nominal safety) is no assurance that a certain quality of design (i.e., level of substantive safety) will be achieved—indicating that such criteria are not sufficient in themselves.

—Jack E. Leisch,
"*Dynamic Design for Safety,*" ITE, 1972

Many design variables that are controlled by standards, warrants, and guidelines have a direct influence and effect on safety. Understanding the concept of safety for all users is not the responsibility of just "safety engineers." It is also the responsibility of all practitioners who make decisions as part of the transportation PDP. This section describes and defines the concepts of *nominal safety* and *substantive safety*, discusses how and why they differ, and examines why each dimension is important in project development.

2.3.1.1 Nominal Safety

In the context of project development, agencies are expected to produce a highway or street design that is "safe" for all users, both current and future. That process is commonly understood to occur by applying best practices, design criteria, and design approaches adopted by the transportation engineering profession. In the United States, highway geometric design has commonly been crafted using AASHTO's *Policy on Geometric Design of Highways and Streets*,[2] as well as its companion document, AASHTO's *Roadside Design Guide*.[3] The Federal Highway Administration's (FHWA's) *Manual on Uniform Traffic Control Devices*[4] defines the specifics of traffic control, signing, pavement markings, and other aspects related to the operation of highways. *The Guide for the Planning, Design, and Operation of Pedestrian Facilities*[5] and the *Guide for the Development of Bicycle Facilities*[6] provide guidelines for the planning, design, and operation of pedestrian and bicycle facilities.

Nominal safety refers to the practice of attributing safety to the referencing and application of such accepted documents.[7] That is, the use of design policies, standards, and guides produces nominally safe transportation designs. Nominal safety—the use and adherence to engineering standards and practices—has value for the following reasons:

- Designs must enable road users to behave legally.
- Designs should not create situations with which a significant minority of road users has difficulties.
- Nominal safety is useful protection against claims of moral, professional, and legal liability.
- Relying on nominal safety may be a temporary necessity when crash frequency and severity consequences are unknown.

A problem with using nominal safety in project development is illustrated in figure 2-2. If designers refer to a dimension or feature as being "substandard," and hence "unsafe," they express a mental model of safety shown by the green line—that nominal safety is an absolute. A designer may also apply that approach when explaining why a particular solution favored by a stakeholder cannot (in the designer's view) be supported.

Engineers who know roadway design but lack knowledge of safety performance may apply the minimum design value for a roadway feature (for example, lane width, curve radius, or stopping sight distance), thereby using a value that they believe that others have concluded will provide a "safe" highway. The inference, and sometimes openly stated view, is that using or retaining a design dimension that is less than the minimum will produce an "unsafe" design. Thus, nominal safety is characterized as an "either/or" proposition, where an approach or dimension is thought of as either "safe" or "unsafe."

That mental model has two serious flaws. The first is the concept that safety is an absolute. The second is the presumptive relationship between substantive safety and nominal safety for most roadway design elements.

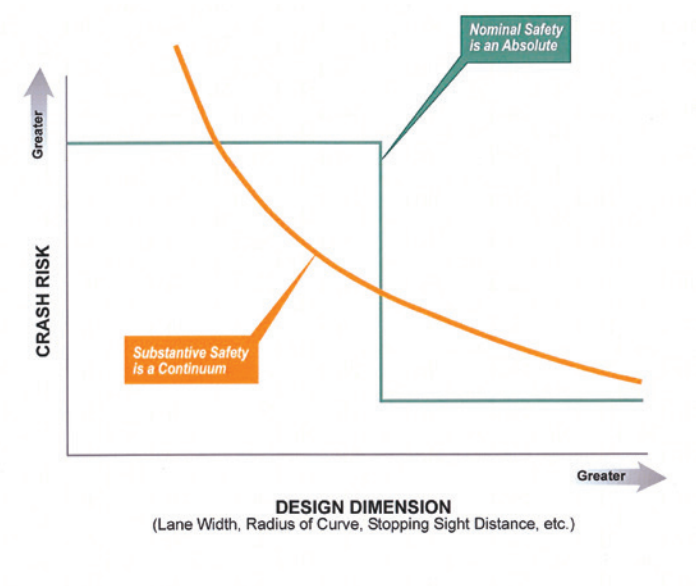
The objective to "upgrade to standards" or guidelines should not be considered requisite, nor should it necessarily be considered a safety issue if the road does not "meet standards." In the past, State departments of transportation have had an attitude that if any improvement project is undertaken, all aspects of the facility must meet minimum standards. In some cases, such projects can be very costly. However, is there truly a need to upgrade to standards if the facility operates at or better than the expected safety performance?

2.3.1.2 Substantive Safety

Substantive safety is the performance of the street or highway as measured by frequency of traffic crashes and their outcomes (severity). Performance is defined and measured according to objective data—the reported crashes at the location or the modeled or predicted number of crashes using science-based methods.

Safety is not an absolute and cannot be measured by nominal safety considerations without also considering the substantive safety knowledge base on design variables and controls.

Figure 2-2. Nominal and Substantive Safety Decision Models



Source: CH2M HILL.

Understanding substantive safety requires knowledge of the relationships between actions, the environment, all modes of travel, and other characteristics and of how each can affect crash frequency and severity (injuries and fatalities). The *Highway Safety Manual* (HSM)[8] is a compendium of science-based knowledge regarding substantive safety of highway facilities. It presents the tools and methodologies for consideration of safety across the range of highway project development activities. The following is an overview of basic knowledge contained in the HSM:

- There is a relationship between crash frequency, traffic volume, geometric design, and period of time. The relationship of crash frequency to annual average daily traffic volume is nonlinear and context specific. Methods that use crash rate (crashes per 1 million vehicle miles) for analysis and decision making have some shortcomings, may not consider context, and can sometimes be misleading.
- Contributing factors to crashes vary by crash type, roadway type, and site type (intersection, roadway segments). Analyses and understanding of appropriate countermeasures require disaggregation between single-vehicle and multivehicle crashes for some roadway types. Further disaggregation by specific crash type may be necessary when considering certain countermeasures or treatments.
- Approaches to dealing with known substantive safety issues should consider not only infrastructure (engineering) countermeasures but also road user education, law enforcement, and emergency medical services—the four E's.
- Analytical techniques, models, and procedures are available for measuring, estimating, and evaluating roadways for crash frequency and crash severity.

The science of substantive safety provides quantitative estimates of roadway safety, which can be used successfully in project development and the detailed comparison of the effectiveness of safety improvements.

Criteria that have a significant influence on the footprint and cost of construction include cross-sectional values (lane and shoulder width, median width, presence of shoulders, accommodation of pedestrians and bicyclists), alignment (horizontal, vertical), and vertical clearances, among others. Design decisions and resulting costs for projects are heavily influenced by providing for those features. Linking investment decisions to substantive safety outcomes, rather than just to standards (nominal safety), offers the opportunity to make better and more cost-effective design decisions.

Substantive safety is also clearly influenced by noninfrastructure conditions or actions. The safety performance of the corridor will be influenced by, for example, the extent to which emergency medical services can access the site of a crash anywhere along the corridor at any time or the ability to enforce known driver behavior issues, such as speeding, aggressive driving, or alcohol or drug use. An agency's design decisions and operations strategy can affect actions by other agencies both positively and negatively.

The transportation professional can study the substantive safety of an existing road or street, in which case the history of observed crashes is an important factor. Alternatively, the substantive safety of proposed alternative designs can be estimated, in effect "predicting" future safety performance to inform decision making. In contrast to nominal safety, substantive safety is defined in direct performance-based terms. Knowledge of the observed and expected substantive safety for an existing facility is objective and science based. The effect of dimensional variances in most design elements is illustrated by the orange line in figure 2-2. Small changes in a dimension will have a modest incremental effect on crash frequency.

Substantive safety knowledge is obtained from the statistical analysis of databases containing crashes reported by police agencies, and that are recorded and maintained by States. Basic information central to understanding the substantive safety profile of a site includes the location of the crash, type of crash, contributing factors, and severity outcomes. Performance benchmarks for comparing a site's substantive safety with what should be expected are used to determine the quality of the safety performance of that site and thereby to facilitate and direct the study process for that site.

2.3.1.3 Factors Influencing Substantive Safety

A substantial body of knowledge now exists that establishes the relationship of roadway elements and traffic operational strategies to crashes and crash severity. Substantive safety

AASHTO' *Highway Safety Manual*

AASHTO's *Highway Safety Manual* (HSM), published in 2010 (figure 2-3), represents the culmination of 10 years of research and development by an international team of safety experts, academics, and practitioners. The purpose of the HSM is to assess the safety effects of transportation project and program decisions. As a tool, the HSM allows planners, designers, and traffic engineers to evaluate the safety effects of decisions throughout the project development process on crash frequency and crash severity. The science-based approaches and tools in the HSM add value to the project development process by explicitly facilitating consideration of safety.

The HSM is organized into four parts:

Part A—Introduction, Human Factors, and Fundamentals of Safety
Part B—Roadway Safety Management Process
Part C—Predictive Methods
Part D—Crash Modification Factors

As the key resource that will allow for quantitative safety performance evaluation, the HSM will do the following:

- Improve the decision-making process for applying safety treatments.
- Demonstrate the effects on safety of various design alternatives.
- Address specific needs.
- Integrate safety elements in the most cost-effective manner.
- Predict the change in crash frequency or severity associated with a particular improvement.
- Allow agencies to do more with less by focusing resources on locations with the greatest potential for safety improvement.

By using the HSM, practitioners can do the following:

- Identify sites with potential for crash frequency or severity reduction.
- Identify factors contributing to crashes and associated potential countermeasures to address those issues.
- Evaluate the change in crash frequency of implemented treatments.
- Conduct economic appraisals of improvements to prioritize projects.
- Calculate the effect of various design alternatives on crash frequency and severity.
- Estimate potential crash frequency and severity on highway networks and the potential effects of transportation decisions on crashes.

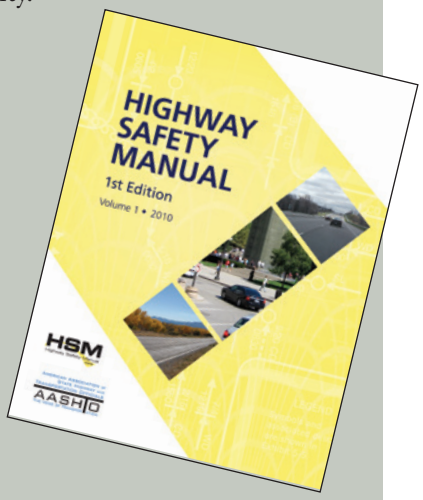


Figure 2-3. Highway Safety Manual

varies by context. For example, the number, types, and severity of crashes expected for a rural two-lane highway will differ considerably from those expected for an urban arterial, a local street intersection, or a rural multilane highway. Key elements of the context include volume and types of vehicles, presence of users such as pedestrians and bicyclists, prevailing speeds, and roadway features. Substantive safety is influenced by the capabilities of drivers, vehicle technologies, effectiveness of law enforcement, and quality of the roadway environment.

Regardless of context, the following basic factors directly influence substantive safety:

- *Volume of vehicular traffic, pedestrians, and bicyclists* is the single most important descriptor of the relative risk of a crash involving each.
- *Crash risk* differs for intersections and roadway segments. Intersections are point locations where conflicts occur. For roadway segments, crash risk is directly proportionate to the length of road.
- *Speed at impact*—as well as whether the crash involves one vehicle striking an object, two vehicles striking each other, or a vehicle striking a pedestrian or cyclist—highly influences the chance of a serious outcome.

Substantive safety can be influenced by the presence or absence of a design feature (for example, a raised median), as well as by the manner in which the roadway's three-dimensional elements—alignment, profile, and cross section—are established. In that way, designers, working with stakeholders, have considerable influence on the safety performance of their solutions.

It should be noted that—although the current knowledge base about substantive safety performance and about the majority of tools and resources for analyzing substantive safety focuses heavily on vehicular travel—such knowledge in no way implies that substantive safety is any less valuable when one considers the context and design of facilities for other modes and users. It is simply related to the amount of current available research, and such research in the first generation of documents and tools for analyzing substantive safety focused on the areas where the most data were available: automobile crash and roadway design data. As more research and information become available about the effects

on safety performance as a result of changes in design elements for transit, bicycle, and pedestrian facilities, additional resources and tools will also become available for use by professionals in the transportation planning and engineering community.

2.3.2 Previous Misconceptions about Safety in Project Development

In the past, misconceptions about safety hindered agencies' abilities to integrate safety objectively into project development. Although many of the concepts and knowledge about transportation safety are nothing new, until recently tools were not readily available to quantify the effects of design changes on safety. The newer science of substantive safety can provide quantitative estimates by which an agency can work to dispel those misconceptions. As noted, safety has traditionally been evaluated on whether a design meets standards or guidelines, thereby establishing whether a facility is safe or unsafe. The following are previous misconceptions about safety:

- Crashes are random events—we can't predict them.
- Poor driver behavior causes most crashes, and we can't do anything about driver behavior.
- A design is unsafe if it doesn't meet design standards.
- Faster (speed) is less safe and will cause more crashes.
- We cannot "trade off safety." Safety must come first in everything we do.
- There are not enough other users (such as pedestrians and bicyclists) to consider spending limited public funds for their safety considerations.
- We use safety standards. They tell us what to do and what not to do.
- Eliminating congestion always improves safety.
- You touch it; you fix it. We must always upgrade to standards when dealing with an existing facility.

The nominal safety of a particular location, as defined by its geometric and operational characteristics, does not in itself define or constitute an issue. In fact, it is commonplace for roadways or intersections designed 30 or more years ago to contain geometric features that were designed to meet an agency's policies at the time, but that are no longer compliant because of subsequent changes in design policies. The principles of substantive safety—whereby the actual performance of a facility is used as the means to measure the need—support the position that "upgrading to standards or guidelines" does not constitute a transportation need, nor should it be the sole reason for a project investment. The nominal safety condition may be a factor in what solution is designed, but it should depend on the substantive safety performance of the road.

2.4 INTEGRATION OF SUBSTANTIVE SAFETY INTO PROJECT DEVELOPMENT

The PDP moves through a series of major steps. Every project begins with the identification of issues. Safety is nearly always an important need, regardless of stated project needs, and it is often a common value among disparate stakeholders. Some projects may be driven by safety issues. Although some projects are not directly driven by a safety issue, safety performance may be affected by or may even influence the actions taken to address the primary issue.

At all levels of project development, substantive safety can be used to inform the process and to facilitate better transportation decisions.

During program development and project planning, substantive safety can be used for the following:

- Network screening and safety emphasis area prioritization
- Investment planning, resource allocation, and program development
- Performance management and continuous process improvement

During project development and delivery, substantive safety can be used to do the following:

- Assess the relative needs for a project.
- Communicate those needs to the public.
- Prioritize work to keep the project within budget.
- Support documentation for design exceptions.
- Monitor, evaluate, and report on safety performance.
- Consider the selection of design criteria and project components.

Substantive safety can accomplish the following:

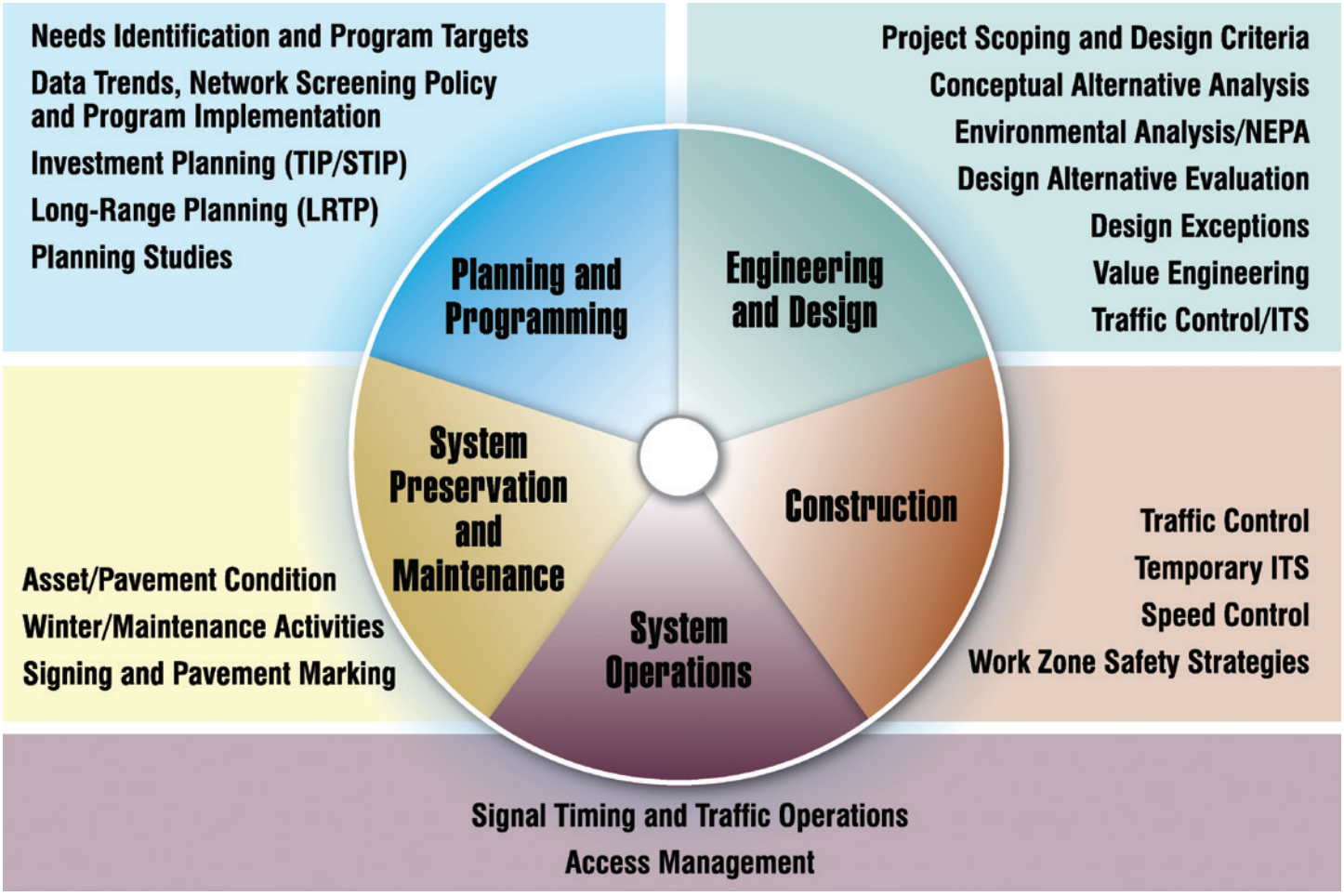
- Quantify relative safety of a facility.
- Demonstrate that the agency is addressing safety needs appropriately.

Figure 2-4 shows the range of opportunities for incorporating substantive safety into project development by defining some of the specific areas within each step where transportation professionals can apply the principles of substantive safety to aid project development.

There is always more than one way to address a recognized safety issue. Selecting the preferred, highest-valued approach requires articulating the project's goals and objectives in performance-based terms. Those goals and objectives should be expressed in quantitative terms that reflect a state-of-the-art understanding of operational and safety performance. Safety-based performance objectives can be developed regardless of the project issue. Indeed, the full range of mobility-enhancing solutions may produce widely varying safety performance outcomes. Such understanding is crucial to avoid an unintended outcome of creating a safety performance issue where none existed before implementation of the project.

To integrate safety into project development, safety performance must be presented and defined in terms that are meaningful to both technical and nontechnical stakeholders. Quantitative safety performance measures should be identified and agreed on early in the PDP so that they can be

Figure 2-4. Application of Substantive Safety in the Project Development Process



Source: CH2M HILL.

Note: ITS = intelligent transportation system; LRTP =long-range transportation plan; NEPA = National Environmental Policy Act; STIP = Statewide Transportation Improvement Program; TIP = transportation improvement program.

readily applied to reach appropriate project-level design and traffic operational decisions, regardless of the project's type or location.

A good decision is an informed decision. Tradeoffs are necessary and inherent to project development. Decision makers need objective measures developed with context in mind in order to balance competing interests in areas such as cost, right-of-way, environmental operations, and safety. The safety performance measures that may best apply will vary by project context.

2.5 TOOLS AND RESOURCES FOR APPLYING SAFETY IN THE PROJECT DEVELOPMENT PROCESS

Tables 2-1 and 2-2 list some of the many analytic tools, references, and resources available to aid highway engineers and other transportation professionals in integrating substantive safety into project development. Those tables provide a snapshot of the best information and analytic methods currently available within a growing knowledge base of research about the application of substantive safety considerations in transportation facility planning and design. The list is not intended to be all-inclusive and is not ordered from best to worst. However, the resources listed are known and accepted methods and tools that have been vetted through the transportation industry and are considered current best practices in substantive safety evaluation and analysis. In subsequent chapters, this report will provide numerous approaches and will refer to case studies included in chapter 10 to illustrate methods for using those basic tools in practical applications at various stages of project development.

Sources such as FHWA, AASHTO, and others were reviewed to compile the lists; tools that were specific to an agency, that had limited application outside of specific jurisdictions, or that were not available "off the shelf" for broad-based industry application have not been included. However, it is recognized that other tools exist or are under development that may have application

Table 2-1. Quantitative Tools and Analytic Methods for Substantive Safety Analysis

	Description
Crash Modification Factor (CMF) Clearinghouse, FHWA http://www.cmfclearinghouse.org/resources_develop.cfm	The CMF Clearinghouse offers transportation professionals a central, web-based repository of CMFs, as well as additional information and resources related to CMFs. A CMF is used for evaluating the effect on safety as a result of changes in design elements and the safety effectiveness of a proposed countermeasure or treatment. A CMF in the clearinghouse can be applied to all roadway and intersection types.
Enhanced Interchange Safety Analysis Tool (ISATe), AASHTO http://www.fhwa.dot.gov/publications/research/safety/07045/index.cfm	ISATe is an automated tool that combines traffic microsimulation and automated conflict analysis. ISATe is used for (a) accessing the safety effects of geometric design and traffic control features at an existing interchange and adjacent roadway network or (b) for predicting the safety performance of design alternatives for new and reconstructed interchanges and for supporting flexible analysis. ISATe is applied to existing or new freeways and interchanges.
HiSafe,[a] Digiwest http://hisafe.org/	HiSafe is a software package that allows users to evaluate segment and intersection designs using Part C of the *Highway Safety Manual* (HSM). HiSafe is used in developing a roadway safety management program and in estimating crash frequency and severity under alternative designs or for future periods. HiSafe is applied to all roadway and intersection types.
HSM Part B Roadway Safety Management Process,[b] AASHTO https://bookstore.transportation.org/collection_detail.aspx?ID=33	HSM Part B is a guide that presents suggested steps to monitor and reduce crash frequency and severity on existing roadway networks as part of the roadway safety management process. HSM Part B is used for identifying improvement sites, diagnosis, countermeasure selection, economic appraisal, project prioritization, and effectiveness evaluation and can be applied to all roadway and intersection types.
HSM Part C Predictive Methods,[b] AASHTO https://bookstore.transportation.org/collection_detail.aspx?ID=33	HSM Part C is a guide that provides a predictive method for estimating expected average crash frequency. HSM Part C is used for estimating the expected average crash frequency, or safety performance of a roadway network, facility, or site. HSM Part C is applied to rural two-lane highways, rural multilane highways, suburban and urban arterials, freeways, and interchanges.
HSM Part D Crash Modification Factors,[b] AASTHO https://bookstore.transportation.org/collection_detail.aspx?ID=33	HSM Part D is a guide that quantifies and evaluates the safety effectiveness of a proposed countermeasure or treatment. CMFs are used for any design or evaluation process where optional treatments are being considered. CMFs are applicable to roadway segments, intersections, interchanges, special facilities, and geometric situations.
Interactive Highway Safety Design Model (IHSDM) HSM Predictive Method Spreadsheet Tools, FHWA www.ihsdm.org	IHSDM is a suite of software tools that uses the HSM predictive method to evaluate the safety and operational effects of geometric design decisions on highways. IHSDM includes six evaluation modules: Crash Prediction, Policy Review, Design Consistency, Traffic Analysis, Driver/Vehicle, and Intersection Review. IHSDM is applied to rural two-lane highways, rural multilane highways, suburban and urban arterials, freeway segments, ramps, and interchanges. Some modules are applicable only to rural two-lane facilities.
Intersection Magic,[a] Pd' Programming, Inc. http://www.pdmagic.com	Intersection Magic is an MS Windows–based PC application for crash records analysis. Intersection Magic is used for creating collision diagrams, identifying and mapping high accident locations, preparing frequency reports, and making presentation graphics.
NCHRP 17-38—HSM Predictive Method Tools, TRB http://www.safetyperformance.org/resources/hsmxlsextended/	NCHRP 17-38 spreadsheets are worksheet tools to apply HSM Part C. NCHRP 17-38 spreadsheets are used to predict crash frequency and safety performance. NCHRP 17-38 spreadsheets can be applied to rural two-lane highways, rural multilane highways, and suburban and urban arterials.
Pedestrian and Bicycle Crash Analysis Tool (PBCAT), FHWA http://www.pedbikeinfo.org/pbcat_us/index.cfm	PBCAT is a crash-typing software product that improves walking and bicycling safety. PBCAT is used for development and analysis of a database containing details associated with crashes between motor vehicles and pedestrians or bicyclists. PBCAT is used for development and analysis of a database containing details associated with crashes between motor vehicles and pedestrians or bicyclists.
Road Safety Audit (RSA); Road Safety Audit Review (RSAR), FHWA http://safety.fhwa.dot.gov/rsa/resources/	An RSA is a formal safety performance evaluation of an existing or future road or intersection by an independent, multidisciplinary team. RSARs are RSAs specific to existing roadways. RSAs are used for addressing safety issues and recommending solutions for all users. RSAs can be applied to any type of facility and during any stage of project development, including existing facilities that are open to traffic.
Roadside Safety Analysis Program (RSAP), AASHTO http://www.trb.org/Main/Blurbs/152743.aspx	RSAP is software that develops an improved microcomputer-based cost-effectiveness analysis procedure for roadside safety. RSAP is used for assessing alternative roadside safety treatments at both point locations and sections of roadway and for developing warrants and guidelines, including those that consider the performance levels of safety features. RSAP is applied to risk-based probabilistic roadside benefit–cost design.

Table 2-1. Quantitative Tools and Analytic Methods for Substantive Safety Analysis *(continued)*

	Description
Safety Planning Documents, FHWA http://safety.fhwa.dot.gov/hsip/	Safety planning documents are guide documents that provide a comprehensive framework for reducing highway fatalities and serious injuries on all public roads. Safety planning documents are used to achieve a significant reduction in traffic fatalities and serious injuries. Safety planning documents are applied to all public roads, including non-State-owned public roads and roads on tribal lands.
Safety Reviews (Final Design/Plan)	Design/plan safety reviews are performed during the detailed stages of project development and are used to evaluate project design for adherence to committed safety improvements and to evaluate changes implemented during final design with effects on safety.
Safety Analyst—HSM Part B Analysis Tool,[a] FHWA http://www.aashtoware.org/Safety/Pages/Annual-Fees.aspx	Safety Analyst is a set of software tools used by State and local highway agencies for highway safety management. Safety Analyst is used for guiding the decision-making process to identify safety improvement needs and to develop a system-wide program of site-specific improvement projects. Safety Analyst is applied to all roadway and intersection types.
Surrogate Safety Assessment Model (SSAM), FHWA http://www.fhwa.dot.gov/downloads/research/safety/ssam/index.cfm?agreement=yes	SSAM is a simulation and analysis tool that combines microsimulation and automated conflict analysis, which analyzes the frequency and character of narrowly averted vehicle-to-vehicle collisions in traffic, so the tool can assess the safety of traffic facilities without waiting for a statistically above-normal number of crashes and injuries to actually occur. SSAM is used to automate conflict analysis by directly processing vehicle trajectory data. SSAM is applied to all roadway and intersection types.
Systemic Approach to System Safety Analysis, FHWA http://safety.fhwa.dot.gov/systemic/resources.htm	The systemic approach is a method for safety planning and implementation. The systemic approach is used for quantifying and improving the benefits of a systemic safety program. The systemic approach is applied to high-risk roadways correlated with specific severe crash types.
Systemic Safety Project Selection Tool, FHWA http://safety.fhwa.dot.gov/systemic/fhwasa13019/	The Systemic Safety Project Selection Tool uses a systemic safety analysis approach that addresses highway safety issues. The Systemic Safety Project Selection Tool is used for planning, implementing, and evaluating systemic safety programs and projects that best meet their capabilities and needs. The Systemic Safety Project Selection Tool is applied to high-risk roadway features correlated with specific severe crash types.
US Roadway (usRAP) Tools Software, AAA Foundation for Traffic Safety http://www.usrap.us/home/	The usRAP Tools software is used for identifying and mapping roadways on the basis of safety performance. The tool assigns a road safety score and star rating and develops risk mapping according to crash density, crash rate, crash rate ratio, and potential savings for crashes involving fatalities and serious injuries. In turn, agencies can use the ratings to develop safer roads investment plans to help them plan highway infrastructure improvement programs that will reduce fatal and serious injury crashes.

[a] *Proprietary software; requires licensing and/or fee.*
[b] *AASHTO publication; requires purchase.*

Table 2-2. Qualitative References and Resources

	Description
BIKESAFE: Bicycle Countermeasure Selection System—FHWA-SA-05-006, FHWA http://www.pedbikesafe.org/BIKESAFE	The *Bicycle Safety Guide and Countermeasure Selection System* is intended to provide practitioners with the latest available information for improving the safety and mobility of those who bike. The online tools provide the user with a list of possible engineering, education, or enforcement treatments to improve bicycle safety and/or mobility on the basis of user input about a specific location.
***Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices*, 7th ed.**, National Highway Transportation Safety Administration, http://www.ghsa.org/html/publications/countermeasures.html	*Countermeasures That Work* is a basic reference that assists State highway safety offices in selecting effective, science-based traffic safety countermeasures for major highway safety areas. It is used for specific behavioral countermeasures and summaries of effectiveness, costs, use, and implementation time. *Countermeasures That Work* is applied to all types of roadways, freeways, and intersections.
Designing Walkable Urban Thoroughfares: A Context Sensitive Approach, Institute of Transportation Engineers http://library.ite.org/pub/e1cff43c-2354-d714-51d9-d82b39d4dbad	*Designing Walkable Urban Thoroughfares* is guidance for designing walkable urban streets while balancing the mixed needs of an urban thoroughfare through a context sensitive solution approach. *Designing Walkable Urban Thoroughfares* is used for improving both mobility choices and community character to create and enhance walkable communities. The manual acts as a how-to document that illustrates best practices for the creation and implementation of walkable, mixed-use streets. Moreover, it is a tool that transportation planners, public works departments, city leaders, and community members can use to design better streets, mitigate traffic, spur economic growth, and act on public health concerns.
Guide for the Development of Bicycle Facilities, AASHTO https://bookstore.transportation.org/	*The AASHTO Bike Guide* provides detailed planning and design guidelines on how to accommodate bicycle travel and operation in most riding environments. It covers the planning, design, operation, maintenance, and safety of on-road facilities, shared-use paths, and parking facilities. Flexibility is provided through ranges in design values to encourage facilities that are sensitive to local context and to incorporate the needs of bicyclists, pedestrians, and motorists.
Guide for the Planning, Design, and Operation of Pedestrian Facilities, AASHTO https://bookstore.transportation.org/	*The AASHTO Pedestrian Guide* provides guidelines for the planning, design, operation, and maintenance of pedestrian facilities, including signals and signing. The guide recommends methods for accommodating pedestrians, which vary among roadway and facility types, and addresses the effects of land use planning and site design on pedestrian mobility.
Integrating Road Safety into NEPA Analysis: A Practitioner's Primer, FHWA http://safety.fhwa.dot.gov/hsip/tsp/fhwasa1136/fhwasa1136.pdf	The *Practitioner's Primer* presents an introduction to the topic of addressing safety as part of the environmental analysis process, as directed by the National Environmental Policy Act (NEPA). It presents basic concepts for including meaningful, quantitative analysis of project safety issues and for taking advantage of the latest tools, research, and techniques for improving road safety within a project's scope. The primer highlights the opportunity for and benefits of linking safety planning to the environmental analysis at every stage of the NEPA process.
Mitigation Strategies for Design Exceptions, USDOT/FHWA http://www.wsdot.wa.gov/publications/fulltext/ProjectDev/Manuals/MitigationManual.pdf	*Mitigation Strategies for Design Exceptions* provides designers with practical information on design exceptions and strategies to mitigate the effect of the design exceptions. *Mitigation Strategies for Design Exceptions* is used for mitigating potential adverse impacts to highway safety and traffic operations. It is applied to mitigation strategies for 13 controlling criteria and design exceptions.
NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, AASHTO http://www.trb.org/Main/Blurbs/152868.aspx	*NCHRP Report 500* documents are a series of guides to assist State and local agencies in reducing injuries and fatalities in targeted areas. *NCHRP Report 500* presents strategies for reducing injuries and fatalities tailored to 22 emphasis areas addressed in AASHTO's Strategic Highway Safety Plan: speeding, motorcycles, head-on crashes, young drivers, bicycles, work zones, alcohol-related crashes, rural emergency medical services, drowsy/distracted drivers, heavy trucks, signalized intersections, seatbelt use, pedestrians, older drivers, utility poles, horizontal curves, run-off-the-road collisions, unsignalized intersections, trees in hazardous locations, drivers with suspended or revoked licenses, and aggressive driving.
NCHRP Report 600: Human Factors Guidelines for Road Systems, AASHTO http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600Second.pdf	*NCHRP Report 600* documents are a suite of guidelines that provide principles and findings related to human factors. *NCHRP Report 600* is used for providing factual information and insight on the characteristics of road users and for facilitating safe roadway design and operational decisions.
NCHRP Report 622: Effectiveness of Behavioral Highway Safety Countermeasures, AASHTO http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_622.pdf	*NCHRP Report 622* is a guidance document that presents methods to estimate costs and benefits of emerging, experimental, untried, or unproven behavioral highway safety countermeasures. *NCHRP Report 622* is used to assist States in selecting programs, projects, and activities that have the greatest potential for reducing highway deaths and injuries. *NCHRP Report 622* is applied to the data sets or records of behavioral highway safety countermeasures.

Table 2-2. Qualitative References and Resources *(continued)*

	Description
***Roadside Design Guide*, 4th ed.**, AASHTO https://bookstore.transportation.org/item_details.aspx?id=1802w	The *Roadside Design Guide* is a synthesis of current information and operating practices related to roadside safety. The *Roadside Design Guide* is used to assist individual highway agencies in developing standards and policies on safety treatments that can minimize the likelihood of serious injuries when a motorist leaves the roadway. The *Roadside Design Guide* is applied to all types of roadside.
Speed Management—A Road Safety Manual for Decision-Makers and Practitioners, FHWA http://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa09028/65.htm	*Speed Management* is an important manual that outlines the importance of speed mitigation and its effect on traffic safety. It is used to assist in determining the issue of excessive speed and to offer improvement. *Speed Management* is applied to assessing speed issues and designing mitigation measures for decision makers.
Toolbox of Countermeasures for Rural Two-lane Curves http://www.intrans.iastate.edu/research/documents/research-reports/rural_two-lane_curves_toolbox_w_cvr2.pdf	The *Toolbox* is a report on curve countermeasures for rural 2-lane highways. It was developed to assist agencies in addressing crashes on rural curves. The main objective is to summarize the effectiveness of various known curve countermeasures. *Toolbox* is applied to rural two-lane highways.
Transportation Planner's Safety Desk Reference—Companion to the NCHRP Report 500 series, FHWA http://tsp.trb.org/assets/FR1_SafetyDeskReference_FINAL.pdf	The *Desk Reference* is a companion document to *NCHRP Report 500* series guides for transportation planners. The reference document describes an overview of transportation safety, the potential roles that transportation planners can play to advance it, a framework for incorporating safety into the transportation planning process, available sources that may be accessed to fund safety programs, and a menu of possible safety strategies.
NACTO Urban Bikeway Design Guide, National Association of City Transportation Officials http://nacto.org/cities-for-cycling/design-guide/	The NACTO Guide address more recently developed bicycle design treatments and techniques. It provides options that can help create "complete streets" that better accommodate bicyclists. Although not directly referenced in AASHTO's *Guide for the Development of Bicycle Facilities*, many of the treatments in the *NACTO Guide* are compatible with AASHTO's *Bike Guide* and demonstrate new and innovative solutions for the varied urban settings across the country.

to substantive safety. Those tools may be addressed and applied on a case-by-case basis as deemed appropriate.

The current knowledge base in quantitative safety is broad with much research and guidance available for practitioners to draw from as they apply safety to transportation project development. However, there are knowledge gaps in areas where tools and best practices may not yet exist for conducting a substantive or quantitative safety analysis, particularly in the area of safety for nonvehicular users. Such gaps should not discourage the practitioner from applying the methods presented in this report, nor should they prevent the use of engineering judgment and professional experience to help bridge the gaps. The tools, resources, and references presented herein are not intended to be all-inclusive. Rather, they should serve as the starting point for understanding the methods and means by which quantitative safety can be integrated into project development while considering context sensitive principles.

2.6 REFERENCES

1. American Association of State Highway and Transportation Officials, *A Guide for Achieving Flexibility in Highway Design* (Washington, DC: AASHTO, 2004).
2. American Association of State Highway and Transportation Officials, *A Policy on Geometric Design of Highways and Streets,* 6th ed. (Washington, DC: AASHTO, 2011) (referred to as the Green Book).
3. American Association of State Highway and Transportation Officials, *Roadside Design Guide*, 4th ed. (Washington, DC: AASHTO, 2011).
4. Federal Highway Administration, *Manual on Uniform Traffic Control Devices* (Washington, DC: FHWA, 2009).
5. American Association of State Highway and Transportation Officials, *Guide for the Planning, Design, and Operation of Pedestrian Facilities* (Washington, DC: AASHTO, 2004).
6. American Association of State Highway and Transportation Officials, *Guide for the Development of Bicycle Facilities*, 4th ed. (Washington, DC: AASHTO, 2012).
7. Ezra Hauer, "Safety in Geometric Design Standards," University of Toronto, December 15, 1999.
8. American Association of State Highway and Transportation Officials, *Highway Safety Manual*, 1st ed. (Washington, DC: AASHTO, 2010).

ORGANIZATIONAL NEEDS FOR INTEGRATION OF SAFETY IN THE PROJECT DEVELOPMENT PROCESS

3

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3.1 INTRODUCTION

The concept of substantive safety offers significant benefits to agencies by providing a method of estimating and understanding the safety implications of project development decisions or actions. Agencies now have a basis for decision making regarding project selection, scope, and basic approach and can more directly integrate safety into the overall project development process (PDP).

However, an organization's ability to integrate performance-based practices—such as substantive safety into project development—can be severely hindered if there is not clear support from leadership and acceptance by the technical staff or if there is limited stakeholder understanding for using performance-based decision making when making transportation planning decisions. Therefore, as organizations begin to integrate substantive safety into project development, they may need to consider changes in their structure, work policies and processes, staff qualification and makeup, technical capabilities, and culture in order to overcome those potential roadblocks.

This chapter has the following objectives:

- Summarize the database needs, specific tools, resources, and capabilities that agencies need to apply the substantive safety approach to project development.
- Identify the process, technical learning, and procedural and culture changes necessary within an agency to fully integrate substantive safety as part of routine project development.
- Develop awareness of the needed data and linkages among databases to take full advantage of substantive or quantitative safety knowledge. Such data are not usually available in forms usable for new industry tools.

3.2 ORGANIZATIONAL CONSIDERATIONS RELATED TO INTEGRATION OF SAFETY INTO THE PROJECT DEVELOPMENT PROCESS

3.2.1 Organizational Opportunities

Most agencies have organizational characteristics that influence the way they do business. Such characteristics include organizational structure, internal business processes,

policies and procedures, legal and risk management procedures, approaches to information technology management, budgetary guidelines and priorities, and technical expertise. Agencies desiring to institutionalize quantitative safety into project development may need to acquire tools and knowledge, collect and maintain additional or new data, train staff members, and possibly reorganize to take full advantage of the state-of-the-art knowledge base. In doing so, they will face many challenges. From an organizational perspective, they may need to address many of the following topics:

- **Culture Change—**For some agencies, adopting performance-based safety metrics will require a cultural change. In project planning and programming, the traditional approach has been reactive: responding to locations that demonstrate a history of high crash frequency or crash rate rather than being proactive, or seeking to understand and address risk factors, before crashes occur. In engineering and design, the standard practice has been to try to improve safety related to the nominal safety performance of a facility or related to whether the design adheres to standards or guidelines. The substantive safety of any action, whether at the program or project level, requires an understanding of its expected safety effects. For some, that approach means adopting new thinking and terminology. For others, it may be necessary for that new approach to be understood at all levels and through all areas of the organizational structure.
- **Stakeholder Acceptance—**Limitations in stakeholder knowledge and understanding may limit the ability to adopt substantive safety performance metrics and to use some tools. Such limitations could be due to a lack of resources and a fear of increased burden, or simply to a limited understanding of methods that may appear "new" and, therefore, are assumed to be untried or unproven.
- **Administrative Priorities—**Administrative priorities may have been developed without explicit consideration of performance-based safety measures or may be so broad as to diminish the effectiveness of performance management or the implementation of available tools. Political pressure may influence selection of program priorities and may work against a logical, performance-based priority system for program development. Agencies now faced with quantifying safety performance will be challenged by how to resolve competing issues, particularly where past practice and associated decisions conflict with new safety performance methods.
- **Organizational Readiness—**Most States have established data collection and management procedures for traffic volume, crash, and roadway inventory data. Few, though, are capable of seamlessly supporting the linkages required among the varying data sets necessary to apply quantitative safety analysis. Changes in data collection and management, executive support, support and buy-in from affected business units within the agency, and funding of projects may be required and will aid in addressing an agency's needs regarding analytical tools, data collection and management, calibration and possible development of quantitative analysis models, and staff training.
- **Policies and Work Processes—**Agencies need to consider adopting safety sensitive policies as part of project programming and prioritization and project development. By adopting safety sensitive policies and guidance that apply at all levels of project development, agencies can integrate substantive safety into the PDP. Policies should be directed at incorporating substantive safety from the beginning of project development, with the message carried through the design standards and criteria the agency uses for design.
- **Partnership—**Integration of quantitative safety into project development will require that partnerships be established between the larger departments of transportation (DOTs) and local agencies, such as counties and municipalities. The challenges that agencies face as they integrate substantive safety into project development may seem daunting. But many of the challenges to be overcome are similar to those encountered with other recent advances in the transportation industry. Experience with new technologies and advancements in project delivery, such as the context sensitive solutions, "Complete Streets," innovative program delivery, and the recent *Highway Safety Manual* (HSM)[1] implementation initiatives, tells transportation professionals that change can be made with success. Lessons learned from other movements can be used to inform change and to help agencies as they proceed with integrating substantive safety into project development.

Many local agencies have fewer data systems and resources and less formalized processes and policies. Design guidance and policies of the respective State agency are already being filtered down and applied to the local agency facilities often as a matter of necessity. Similarly, in the course of integrating safety into project development, it will naturally be the DOTs that must take the initiative to lead the change in both process and culture that is required to effectively integrate safety into project development and to ensure that that knowledge and experience be passed on to local agencies for use in their own transportation project development and management practices. Through partnerships with local agencies, DOTs and other larger agencies can provide access to guidance, resources, and lessons learned.

3.2.2 Safety Management Requirements for Agencies

3.2.2.1 Agency Structure and Resources

Larger agencies desiring to institutionalize quantitative safety into project development may require some reorganization to take full advantage of the state-of-the-art knowledge base in substantive

safety, whereas smaller agencies may be faced with limited resources and available staff members. Depending on the agency, a change may need to occur either in specific areas or across the agency as a whole. For that reason, it is critical that an agency perform a self-assessment of its readiness to adopt quantitative safety as a performance metric, with a focus on considerations such as the following:

- Leadership
  - Is a champion in place who is at the executive leadership level and who is committed to integrating safety into project development?
- Organizational structure and support
  - Does a structure exist within the organization that will support integration of quantitative safety at all levels of project development?
  - Are adequate staff resources and sufficient support available?
  - Do staff members at all levels support the initiative, and if not, what is necessary to make that change (such as policy and procedures, training, communication, leadership)?
- Policy and procedures
  - Are the existing policies safety sensitive, or will changes need to be made?
  - Do existing publications, design manuals, and guidance documents promote flexibility in design and context sensitive solutions and in substantive safety analysis throughout project development?
- Cost of implementation
  - Are the funding policies in place, or will changes need to be made?
- DOT/local agency relationships
  - Are DOTs reaching out to the local agencies to educate them regarding the tools, processes, and techniques?
  - Do local agencies know who or which DOT counterpart can provide assistance?
  - Have local agencies organized a peer group to provide and share information, experiences, and best practice?

Once an agency has completed the self-assessment and gaps are identified, an action plan should be developed for effecting change in areas where a need is identified.

Regardless of size, the integration of safety into project development is not only a bottom-up initiative but also a top-down initiative. Integration of safety requires strong leadership; a clear mission, vision, and goals; and a well-defined organizational structure, regardless of whether the organization is an army of many or simply a few dedicated individuals.

Enlightened and committed leadership with an understanding of the benefits of a performance-based approach to safety can help remove and redirect institutional barriers that may impede effective implementation; can rally interdisciplinary support from across an agency or between supporting agencies; and can facilitate the necessary policy, procedural, and legislative changes that may be necessary to change the culture. Leadership support and ongoing communication activities are critical. An organization's senior leadership should support integration and should communicate to staff members the value and importance of integrating quantitative safety into project development.

3.2.2.2 Knowledge and Training

Data Needs. The integration of substantive safety into project development is a data-driven process. Full implementation of the predictive methods outlined in the HSM, Part C, requires collection and maintenance of core databases describing the street and highway system, crashes and their characteristics, traffic volumes, and traffic control devices. That is not to say that to apply those methods cannot be accomplished with lesser resources. Even if all an agency has is 2 years of "black spots" on a map and a technical staff of two, those resources can be useful. The roadway inventory, traffic volume, crash, and traffic control (asset) inventory databases to support substantive safety needs can be tailored to support the level of analysis the agency desires to achieve.

Two key resources are available to guide agencies in making improvements to their crash and roadway inventory data systems:

- The *MMUCC Guideline: Model Minimum Uniform Crash Criteria*[2] presents a uniform approach to crash data collection for the purpose of generating accurate, reliable, and credible data sets for use in making highway safety decisions. It recommends a minimum set of standardized data elements implemented voluntarily by an agency to promote comparability of crash data across State agencies and at the national level.
- The *Model Minimum Inventory of Roadway Elements—MMIRE*[3] does for roadway inventory and traffic data what the MMUCC does for crash data. The MMIRE defines the critical roadway inventory and traffic data elements needed by State and local jurisdictions to meet current safety analysis needs and data needs required by the new quantitative safety analysis tools.

Additionally, the Federal Highway Administration's (FHWA's) Office of Safety established the Roadway Safety Data Program to advance State and local safety data systems and safety data analysis and evaluation capabilities. (More information on that program can be found on the Roadway Safety Data Program website, http://safety.fhwa.dot.gov/rsdp/about.aspx.)

Chapter 4 presents more detail on data collection to support substantive safety analysis, including how agencies are adapting the MMUCC and MMIRE procedures to address limited data availability and resources.

Inevitably, the availability of detailed data will support a more statistically reliable project alternative and an increased potential for crash reduction. The data needs for using the advanced methods in the HSM (the predictive methods in Part C of the HSM) depend on the data needs associated with safety performance functions (SPFs) and associated crash modification factors (CMFs). The HSM presents SPFs and applicable CMFs for use in predicting crash frequency by particular facility and site type. SPFs are models to predict crashes developed for a given set of roadway conditions (also known as base conditions), and CMFs are used to adjust the result for different roadway conditions. The data elements needed for that level of quantitative analysis are those that describe the base conditions of the particular SPF and the input necessary to calculate the applicable CMFs.

The specific data needs for analysis will depend on the stage of project development. For example, assessments at the planning level will require fewer data than will alternatives assessment at the detailed design stage. Although the ease of access to those data sources can affect the range of analysis approaches that can be used in the assessment and level of detail, the amount and level of detail in data collection can still be scaled to fit. The form and format of all data fall under the guidance provided in the MMUCC and MMIRE, and agencies can use that information to develop a data management plan to fit their agencies' available resources. Engineering judgment and default data values can be applied where data are missing and can still provide meaningful insight into safety performance. The most important element is that agencies begin to use quantitative safety performance to make project decisions.

Tools and Resources. Integration of substantive safety into project development requires access to tools capable of providing supporting analysis and the level of detail necessary for calculating and evaluating performance-based metrics. A table of tools and references available to the practitioner in the application of quantitative safety is included in chapter 2.

Skills and Experience (Training). Adequate skill level and experience in data collection and substantive analysis are essential to the successful integration of substantive safety into project development at all levels. They require a staff that is trained and knowledgeable in safety-based concepts, that can communicate safety, and that can facilitate stakeholder discussions about transportation safety. They will also require other project development staff members who are knowledgeable about safety, so that their solutions reflect meaningful, substantive safety needs.

The use of the HSM does not necessarily require advanced statistical knowledge, but a fundamental knowledge of safety and the HSM are necessary to perform an analysis. The level of technical expertise needed by the individual or group within the agency will depend on the level of analysis performed. In some cases, the required technical expertise in a particular section, division, or bureau will amount only to having an understanding of how to interpret results rather than to being able to perform the analysis itself.

FHWA's *HSM Training Guide*[4] is a compilation of current HSM-related courses available through the FHWA Resource Center, National Highway Institute (NHI), and Institute of Transportation Engineers (ITE). It also includes a description of the courses and identifies key focus groups that will benefit from HSM training.

In addition to using the training and resources available through FHWA, NHI, and ITE, it may be effective to provide aid through metropolitan planning organizations, councils of governments, or specialized State-level agencies that are dedicated to aiding counties and municipalities. Other resources, such as the Local Technical Assistance Program, can provide additional opportunities for knowledge and skill transfer to local public agencies.

3.2.2.3 Communication

Regardless of structure, engagement at all levels of an organization requires the ability to communicate safety considerations and analysis findings in straightforward and simple terms. Such communication improves the likelihood of adoption and use of the most effective tools in future planning and decision making.

3.2.2.4 Budgetary Considerations

The available budget would likely influence how an agency approaches implementation and the scale of implementation that will be considered initially and over the longer term. The following are examples of budget-related considerations:

- How will the agency fund initial activities to support implementation? Will funds come from Federal, State, local, or other sources? Do the funds have special requirements that the agency must consider?
- Can the agency phase in implementation to accommodate budget availability?
- How does the agency prioritize expenditures for change during times of dwindling resources? Can economies of scale be achieved?
- How would implementation of increased consideration of safety inform decision makers who are influential in the budgeting process that the investment is appropriate and beneficial to the agency and to the needs of the users?
- How will the agency (in the case of a DOT) support integration and implementation at the local level? Are there requirements for funding to local agencies that necessitate

changes to the way that funding is allocated and the support that the State agency should provide?

Agencies may consider integrating safety into project development in phases to distribute the economic impact over multiple years. For example, implementation of the HSM in a particular organization may start with raising awareness among top management and staff about the HSM. In a second phase, the agency may demonstrate the use of the HSM on selected pilot projects or specific programs. At the same time, the agency may initiate research projects to develop or calibrate SPFs or to evaluate the usability of a particular software tool to support analysis using the HSM.

3.3 BEST MANAGEMENT PRACTICES FOR INTEGRATING QUANTITATIVE SAFETY INTO THE PROJECT DEVELOPMENT PROCESS

A considerable amount of information on incorporating quantitative safety into project development can be gleaned from the efforts associated with the national movement to implement the HSM and performance-based safety analysis. AASHTO and FHWA have each developed guidance documents to aid agencies in implementation of performance-based safety into project development. Lessons learned from States and local practitioners that have committed to and are successfully implementing the HSM into the PDP indicate that key guiding principles and management strategies exist that, when used, increase the chances of successfully implementing quantitative safety into program policies and procedures. The principles and management strategies used to integrate the HSM into project development apply to any quantitative safety analysis.

3.3.1 Guiding Principles to Integration of Safety into Project Development

Agencies should strive to incorporate the following guiding principles[5] in their implementation efforts:

- **Anticipate and Embrace Culture Change—**Many substantive safety concepts are new and may run counter to the staff's understanding of safety. Staff training should carefully explain HSM concepts in their proper context and should stress that the HSM does *not* replace design manuals and standards but rather supplements them.
- **Use a Consistent Technical Approach—**Predictive methods, assumptions, use of common databases, common CMFs, and common benefit-cost approaches are all important for both internal purposes and external credibility.
- **Encourage Gradual Change—**Agencies will have varying levels of quality and quantity of necessary data and information technology systems. Changes in policies, use of the quantitative safety analysis, and staff training should not "outpace" the ability or progress of the data and decision-support systems. Seek to establish and then maintain momentum in implementation.
- **Manage Training—**Not everyone needs to be an expert in the HSM, but most people will benefit from a basic knowledge. All practitioners should understand the concept of substantive safety. Agencies, including local agencies, should consider how the HSM will be used, who within the organization (by position, by location) should have a deep understanding, and how their internal experts will be used. Agencies should also consider how others might benefit from the knowledge base without having to undergo extensive training.
- **Learn from the Successes of Similar Agencies—**It is not necessary to reinvent the wheel to make those changes. Other agencies have already done the work and provide valuable lessons to learn from. The FHWA's Safety Program can provide some of that information, as can States and agencies that have successfully advanced through the changes about to be pursued. The National Cooperative Highway Research Program's Project 17-50, *Lead States Initiative for Implementing the Highway Safety Manual*, brought together representatives of States preparing for and implementing the quantitative safety–based safety analysis tools in the HSM for information sharing as a peer exchange. Since then, that group has worked with AASHTO and FHWA to produce documentation chronicling its implementation efforts and to provide information and examples to other highway agencies, including a user's guide for the HSM, which was developed on the basis of the experiences of the States under Project 17-50 (http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP17-50_UserGuide.pdf).

3.3.2 Strategic Management Practices

Agencies that are successfully implementing quantitative safety into project development have executed similar strategic management approaches[6] involving the following:

- Identify and empower a champion who will commit to integrating quantitative safety into the PDP.
- Develop and execute an implementation plan.
- Examine and revise agency policies and resources.
- Examine risk management and legal issues.
- Examine data, information technology, and analytical tools.
- Assess budgets and phased approaches to implementation.
- Identify technical expertise needs and sustainability of technical expertise.
- Identify organizational needs and issues.

3.3.3 Transportation Asset Management and Safety Management Systems

The clear trend in surface transportation is to move toward performance-based decision making. In the context of safety,

that move translates into a need to develop data systems and decision-support tools, as well as project development processes that incorporate crashes—both those that have occurred and those expected or predicted. As agencies proceed toward integrating safety into their project development processes, they are realizing the need for safety assets in their asset management programs.

With the emergence of the HSM, the introduction of substantive safety performance, and an emphasis on improved crash and related data systems, it is now possible and indeed important to think of substantive safety performance in the same way that infrastructure asset management (bridges and pavements) is considered. Programming priorities and specific actions going forward should include an assessment of actions that would influence safety performance. The costs and expected economic benefits of those actions over the life of a project should be estimated, with the results incorporated into program decisions that already include pavement repair and replacement, bridge management and replacement, and similar projects.

3.4 REFERENCES

1. American Association of State Highway and Transportation Officials, *Highway Safety Manual*, 1st ed. (Washington, DC: AASHTO, 2010).
2. U.S. Department of Transportation and Governors Highway Safety Association (GHSA), *MMUCC Guideline: Model Minimum Uniform Crash Criteria*, 4th ed. (Washington, DC: USDOT, June 2012).
3. Federal Highway Administration, *Model Minimum Inventory of Roadway Elements—MMIRE* (Washington, DC: FHWA, August 2007).
4. Federal Highway Administration, HSM Training Guide (Washington, DC: FHWA, 2011), http://safety.fhwa.dot.gov/hsm/training/hsmguide.pdf.
5. Federal Highway Administration, *HSM Implementation Guide for Managers* (Washington, DC: FHWA, 2011).
6. Ibid.

PLANNING AND PROGRAMMING

4

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4.1 INTRODUCTION

Project development is the process a project follows from planning through design to construction. Planning and programming are the first phase in project development (figure 4-1) and involve analyzing conditions, setting goals, identifying strategies or project candidates, and—ultimately—establishing a program of policies and projects to reach an agency's established goals. Transportation agencies are increasingly applying the concept of performance management, which is supported by data, to support decisions made in developing transportation policy, plans, and programs geared toward achieving desired outcomes. That performance-based planning and programming approach makes project and program delivery more responsive to desired outcomes, informs investment decision making, helps focus staff on leadership and agency priorities, and provides greater transparency and accountability to the public.

The performance-based approach to project development provides an opportunity for agency staff to integrate substantive safety into the decision-making and project development processes. Substantive safety knowledge provides the information to more effectively integrate proven safety features into projects. Likewise, that knowledge can aid in the identification of costly project elements that are believed to improve the safety performance but that actually have no or limited substantive safety benefit. In the latter case, agencies may elect to eliminate the costly elements that do not significantly address safety and redirect the funds to deferred projects where noticeable or significant gains could be accomplished.

This chapter has the following objectives:

- Describe what the steps are within the planning and programming phase of project development and how substantive safety can be integrated into each step.
- Show how safety considerations are integrated into the planning and programming phase of project development through a safety-conscious decision-making process.
- Provide an overview of the available tools and resources that can be used to help integrate safety into planning and programming.

4.2 OVERVIEW OF PLANNING AND PROGRAMMING

Transportation planning and programming are an integrated process that should be completed for purposes such as air quality management, asset management, freight movement, transit planning, pedestrian and bicycle planning, investment programming, congestion mitigation, land use planning, highway/roadway planning, long-range transportation planning, intermodal transportation planning, and safety improvements.

Figure 4-1. Planning and Programming: The First Phase in the Project Development Process

Source: CH2M HILL.

Regardless of the type or purpose of planning and programming, the basic transportation planning steps include (a) issue and need identification (*What do we need to accomplish?*), (b) data collection and analysis and project formulation–general project planning (*How are we going to accomplish the desired results?*), and (c) programming and prioritization (*What do we need to do to achieve the desired results?*). Each step has unique aspects, depending on the type of planning and programming to be completed; yet opportunities exist to integrate substantive safety information into the decision framework. The planning and programming phase has four key steps:

- Purpose and need identification
- Data collection and analysis
- Project formulation
- Programming and prioritization

This chapter reviews those primary steps within the planning and programming phase and shows where and how substantive safety can be integrated into planning and programming processes. The following paragraphs provide a general overview of typical activities in each of the four steps. At the conclusion of this document, case studies are provided that illustrate practical examples of real applications of substantive safety to projects in planning and programming.

4.2.1 Purpose and Need Identification

Each planning activity addresses a specific transportation-related need; therefore, the first step includes setting goals and objectives and identifying performance measures specific to the planning topic. In doing so, safety can be an explicit consideration in both the goals and performance measures.

Agencies undertake specific planning activities for various reasons. Federal law requires both statewide plans (strategic highway safety plans [SHSPs], long-range transportation plans [LRTPs], and highway safety plans) and regional plans when certain conditions are met (metropolitan transportation plans [MTPs], congestion management plans [CMPs], and air quality plans in nonattainment areas).

Transit plans, pedestrian plans, and freight movement plans, among others, reflect the values of agencies and stakeholders in the study area, whereas asset management plans strive to maintain a state of good repair. A need or desire to improve network connectivity or corridor performance may result in regional or corridor transportation plans. Required or not, it is good practice for State and local agencies to develop and regularly update multimodal plans to meet the needs and goals of their areas.

Although the needs addressed by the plan vary as much as the plans themselves, safety performance need not be a factor only in safety planning. Asset management and regional and corridor plans may incorporate systemic safety principles into the recommended project type. Specialty plans—such as transit, pedestrian, bicycle, or freight—should identify priority countermeasures and strategies that would be expected to improve safety performance when incorporated into the resulting project. The effect of policies in LRTPs and metropolitan transportation plans on expected regional crash patterns can be a consideration in decision making, especially when policies substantially influence the vehicle miles traveled.

4.2.2 Data Collection and Analysis

A basic principle in the analysis is the identification of trends and targets, including the forecasting of future safety performance. The range of data collected and analyzed for the different types of planning and programming varies as much as the purpose of and need for each plan type. However, a set of core transportation data should be used that covers crash, geometric, and volume data for projects regardless of the planning type. Traffic volume is an important input in nearly every type of transportation planning activity. Likewise, traffic volume data are one of the strongest predictors of safety performance—that is, crash frequency. As planning activities use data to determine the effects that alternatives and policies have on travel patterns, mode choice, traffic volumes, and—ultimately—vehicle miles traveled can also be used to estimate the safety performance of various alternatives. At a basic level, vehicle miles traveled and average regional crash rates for each facility type can estimate safety performance for alternatives or scenarios. Alternatively, more advanced methodologies contained in the *Highway Safety Manual* (HSM)[1] can predict crash frequency.

If agencies need guidance on priortizing data elements for predictive analysis, the Florida Department of Transportation (DOT) prepared a ranking on the importance of all variables used by the HSM models. The Florida DOT's ranking of data elements (shown in tables 4-1 and 4-2) is first separated by the segment and intersection models and, within each category, by the various facility subtypes included in the HSM. The tables summarize the data needs for developing safety performance

Table 4-1. Sample Summary of the Ranking of Variables for Segments

Data Variable	Site Subtype[a]						
	R2U	R4D	SU2U	SU3T	SU4U	SU4D	SU5T
Segment length	1	1	1	1	1	1	1
Average annual daily traffic	2	2	2	2	2	2	2
Lane width	6	7	–	–	–	–	–
Shoulder type	7	NR	–	–	–	–	–
Shoulder width	4	3	–	–	–	–	–
Presence of two-way left-turn lane	10	–	–	–	–	–	–
Median width	–	4	–	–	–	6	–
Presence of lighting	8	6	6	6	6	7	6
Roadside fixed object density	–	–	4	4	4	4	5
Speed limit	–	–	7	8	7	9	7
Presence of on-street parking	–	–	8	7	8	10	NR
Presence of automated speed enforcement	13	5	9	NR	NR	8	8
Presence of passing lane	9	–	–	–	–	–	–
Presence of short four-lane section	11	–	–	–	–	–	–
Presence of centerline rumble strip	12	–	–	–	–	–	–
Roadside hazard rating	5	–	–	–	–	–	–
Driveway density	3	–	–	–	–	–	–
Number of major driveways	–	–	5	5	5	5	3
Number of minor driveways	–	–	3	3	3	3	4
Horizontal curve	NR	–	–	–	–	–	–
Vertical grade	NR	–	–	–	–	–	–

Source: Florida Department of Transportation, "Improved Processes for Meeting the Data Requirements for Implementing the Highway Safety Manual (HMS) and Safety Analyst *in Florida," 2014.*

[a] *R2U = rural two-lane undivided; R4D = rural four-lane divided; SU2U = urban and suburban two-lane undivided; SU3T = urban and suburban three-lane with two-way left-turn lane; SU4U = urban and suburban four-lane undivided; SU4D = urban and suburban four-lane divided; SU5T = urban and suburban five-lane with two-way left-turn lane. NR indicates not ranked;–indicates that the variable is not used for that specific site subtype.*

Table 4-2. Sample Summary of the Ranking of Variables for Intersections

Data Variable	Site Subtype[a]		
	R3ST	SU3ST	SU4SG
Average annual daily traffic: major road	1	1	1
Average annual daily traffic: minor road	2	2	2
Intersection skew angle	5	–	–
Number of approaches with left-turn lanes	4	3	6
Number of approaches with right-turn lanes	3	4	3
Presence of lighting	6	5	NR
Presence and type of left-turn signal phasing	–	–	5
Use of right turn on red signal operation	–	–	10
Use of red-light cameras	–	–	7
Number of bus stops within 1,000 feet	–	–	4
Presence of school within 1,000 feet	–	–	8
Number of alcohol sales establishments within 1,000 feet	–	–	9

Source: Florida Department of Transportation, "Improved Processes for Meeting the Data Requirements for Implementing the Highway Safety Manual (HMS) and Safety Analyst *in Florida," 2014.*

[a] *R3ST = rural two-lane three-leg stop-controlled intersections; SU3ST = urban and suburban three-leg stop-controlled intersections; SU4SG = urban and suburban four-leg signalized intersections. NR indicates not ranked; – indicates not used for that specific site subtype.*

The data collection and analysis process should focus on identifying and prioritizing what is needed for the predictive safety analysis. The process is scalable, and analysis can be completed using default or assumed values when available data are limited.

functions (SPFs), which are equations used to predict the average number of crashes per year at a location as a function of exposure and, in some cases, intersection and roadway characteristics.[2]

Determining the importance of one subtype versus another subtype (rural two-lane highways versus urban/suburban four-lane divided) will depend on the individual agencies, including the context of their road network and available resources (see table 4-3).

When data elements used by the SPFs are not readily available, the HSM often provides reasonable assumptions about typical geometric, volume, or land use conditions that can yield usable results for scenario comparison during the planning and programming phase. It is important to note that the process is scalable, and analysis can be completed using default or assumed values when available data are limited. Quantitative analysis, even if estimated, provides valuable insight into potential design decisions and is still far better than traditional approaches using only qualitative safety information.

4.2.3 Project Formulation

Transportation planning results in recommended projects, policies, and programs, which are identified in cooperation with partners and stakeholders. The recommendations should address the needs established at the beginning of the planning process, including safety. Depending on the plan type, recommendations may include programs and policies as a framework for guiding project development and programming throughout the State, region, and city and for multiple disciplines within the agency. Other plans—such as asset management plans, regional connectivity plans, and corridor plans—often suggest location-specific recommendations or range of alternatives.

Although recommendations might be location specific, the project may often be described more as a concept than as an actual project. Transit plans, pedestrian plans, and freight movement plans may include a mix of both types of recommendations—program and policy and concepts for specific locations. Planners can incorporate substantive safety into both types of recommendations. For example, a statewide LRTP may establish a policy or priority to use shoulder, edge line, or centerline rumble strips wherever reasonably feasible. In a similar fashion, a corridor plan could highlight the safety performance benefits if rumble strips were added to the corridor. Local transit plans or bicycle plans, which may identify priority corridors for future development with the design details still to be decided, provide an opportunity to mention best practices.

With the growing knowledge base regarding substantive safety of countermeasures and strategies, plans could reference pedestrian improvements near transit stops that have been demonstrated to reduce related crashes (such as countdown timers at signalized intersections, rectangular rapid-flashing beacons, and median islands at midblock crossings) and best practices for bicycle accommodations (such as bicycle tracks in high-volume, high-speed corridors; appropriate use of sharrows [shared lane pavement markings]; or safety benefits of bicycle lanes).

Table 4-3. Listing of Fundamental Data Elements for Highway Safety Improvement Program

Roadway Segment	Intersection
Segment ID*	Intersection ID
Route Name*	Location
Alternate Route Name*	Intersection Type
Route Type*	Date Opened to Traffic
Area Type*	Traffic Control Type
Date Opened to Traffic	Major Road AADT
Start Location*	Major Road AADT Year
End Location*	Minor Road AADT
Segment Length*	Minor Road AADT Year
Segment Direction	Intersection Leg ID
Roadway Class*	Leg Type
Median Type	Leg Segment ID
Access Control*	**Ramp/Interchange**
Two-Way vs. One-Way Operation*	RampID*
Number of Through Lanes*	Date Opened to Traffic
Interchange Influence Area on Mainline Freeway	Start Location
AADT*	Ramp Type
AADT Year*	Ramp/Interchange Configuration
	Ramp Length
	Ramp AADT*
	Ramp AADT Year

** Highway Performance Monitoring System full extent elements are required on all Federal-aid highways and ramps located within the grade-separated interchanges, i.e., National Highway System (NHS) and all functional systems excluding rural minor collectors and locals.*

Source: Guidance Memorandum on Fundamental Roadway and Traffic Data Elements to Improve the Highway Safety Improvement Program, August 1, 2011.

4.2.4 Programming and Prioritization

It is generally understood that in any given period, the needs or desires associated with the community values will exceed the resources and ability of the transportation agency to fully respond with appropriate projects. As such, investment programming entails the allocation of limited funds and staff resources across a full range of projects or project types:

- For State DOTs: the Statewide Transportation Improvement Program, capital improvement program, transportation improvement program, and Highway Safety Improvement Program (HSIP)
- For local agencies: the capital improvement program

Investment programming is done in many ways. For States, for example, "set-aside" programs may be established, such as pavement and bridge preservation programs and HSIP, or through a political process in which decision makers choose one project over another. For local capital improvement programs, portions of the total may be established for each type of project (with transportation as one category), and projects may be selected and prioritized within each category. Or all types of projects may be prioritized together within the entire amount of the program. Specific transportation projects are often proposed by various stakeholders and typically reflect studies of projected transportation needs, desired land development outcomes, or identification of transportation needs.

Best-practice investment programming relies on substantive safety and explicitly considers the crash or societal costs estimated for projects or scenarios as an input into the prioritization process. The monetary value assigned to safety can consider all crash severities, down to and including property damage crashes, or it can focus on the most severe crashes. However, current direction for safety funds is to reduce the most severe crashes—those crashes resulting in one or more fatalities, in incapacitating injuries, or in both. To develop safety costs for use in investment programming, agencies generally apply, if possible, locally determined values that are consistent with local priorities. However, when local values are unavailable, resources such as the HSM[3] and the National Safety Council can be used to develop crash cost values.

4.3 SUBSTANTIVE SAFETY CONSIDERATIONS

Integrating substantive safety into transportation planning and programming can happen in any of the four steps. Table 4-4 summarizes where the various analysis applications of substantive safety can be incorporated into each step, and the strength of the relationship each application has relative to the associated step. Those approaches will be discussed in more detail throughout this chapter, including specific technical resources and tools that can be used in applying substantive safety to planning and programming.

4.3.1 Integration of Safety into Planning and Programming

Integrating substantive safety into transportation planning provides agencies with the ability to screen their transportation network and to identify and prioritize those locations where crash reductions may be achieved through the implementation of safety countermeasures or programs of countermeasures. For agencies considering implementing or modifying their policies, substantive safety allows for the quantitative (as opposed to qualitative) determination of decisions regarding the anticipated changes in crash frequency or severity. The intent is to achieve quantifiable safety effects, similar to what has been done in the areas of traffic operations, economics, cost estimation, and environmental impacts.

The Federal Highway Administration (FHWA) promotes a decision-making framework to integrate a safety focus into transportation agencies' planning and programming. The *Safety Focused Decision Making Guide*[4] presents a five-step process to accomplish that goal and even identifies supporting

Table 4-4. Application of Substantive Safety Analysis and Tools to Transportation Planning and Programming

	Four Steps of Transportation Planning and Programming			
Analysis Applications	Purpose and Need Identification	Data Collection and Analysis	Project Formulation	Programming and Prioritization
Network screening	■	○	■	●
Diagnosis/crash analysis	○	○	■	■
Road safety audits	■	■	○	●
Countermeasure development	●	●	○	■
Economic analysis	●	●	■	○
Roadway design context considerations	■	○	○	●
Design element considerations	●	■	○	●
Alternative analysis with predictive models	●	○	○	■

○ *Highly useful and important analysis task*
■ *Moderately important task*
● *Potentially useful task depending on circumstances*

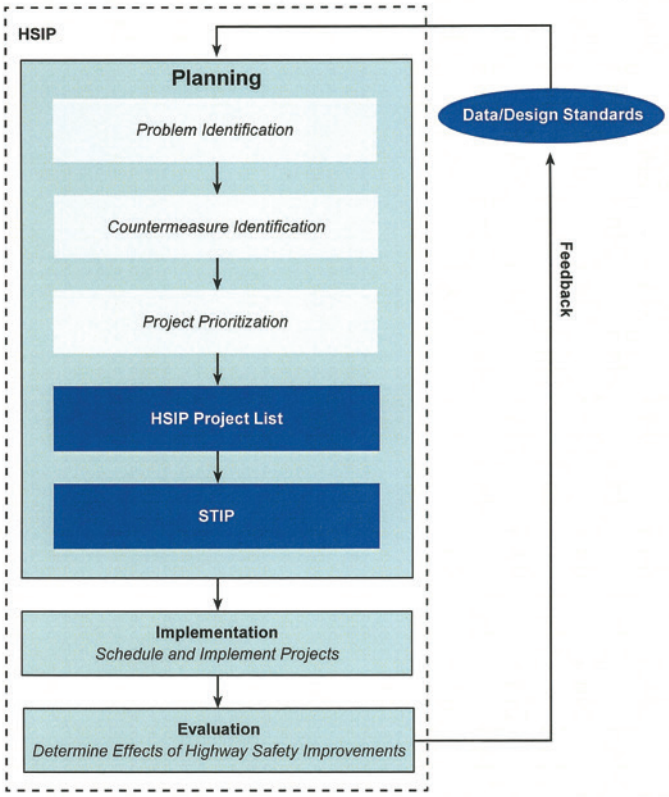
safety-planning tools (figure 4-2). Several notable practices and examples also illustrate how agencies already embrace the fundaments expressed within the guide.

When one is incorporating substantive safety performance into transportation planning, it is important to understand the basic safety planning process. The *Highway Safety Improvement Program Manual*,[5] which is published by FHWA, outlines the basic safety planning process (figure 4-3). The analysis steps—problem identification, countermeasure identification, and project prioritization—result in the HSIP project list for State DOTs. That list ultimately becomes part of the Statewide Transportation Improvement Program. Local agencies can produce project lists using the same approach or can have some local projects that become part of the State DOT's HSIP project list. Within safety planning, FHWA supports two basic approaches.

The more traditional approach directs investments to candidate locations in response to past safety performance. That approach, often referred to as "reactive safety" but now known as the "site analysis approach," has the advantage of directing safety investments to locations with a pattern of treatable crashes in excess of an expected frequency threshold or rate of crashes. Recent uses of SPFs have improved the reliability of the approach to focus on locations and strategies where safety investments can achieve meaningful and measureable results. To support that approach, States, cities, or counties regularly publish lists or maps of eligible locations and the threshold values (greater than X crashes per year or greater than Y crashes per unit of exposure).

That information is readily available during the planning process and can guide in identifying existing roadway segments and intersections with known safety deficiencies—those locations with safety performance statistics that exceed the threshold values identified in the HSIP or local document.

Figure 4-3. Highway Safety Improvement Program Process

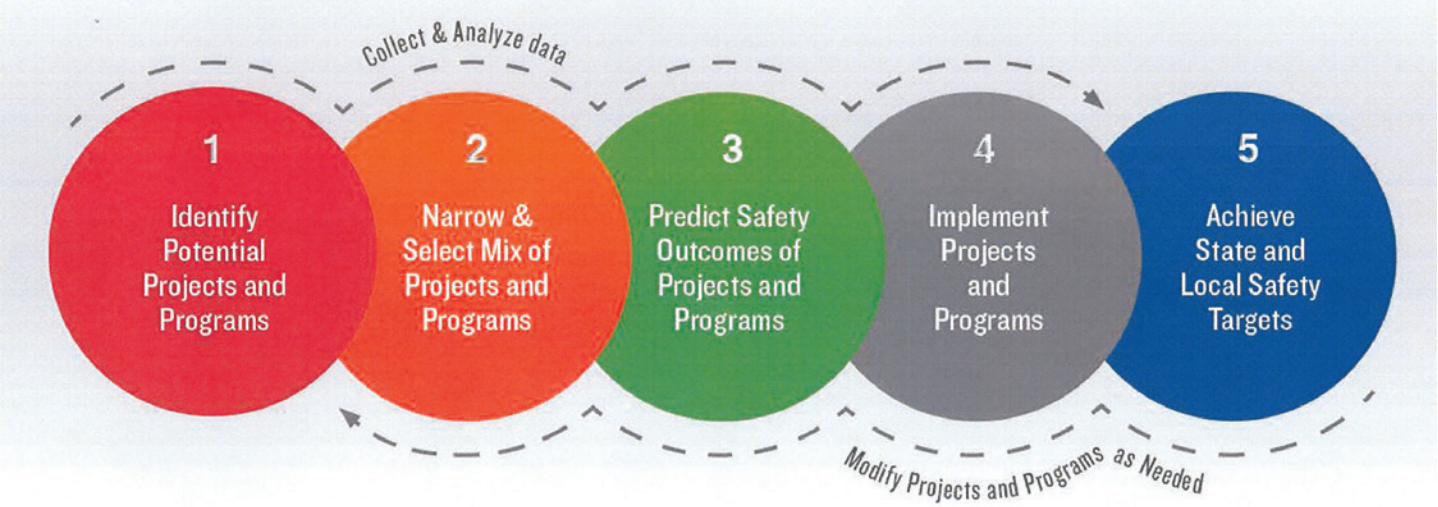


Note: HSIP = Highway Safety Improvement Program; STIP = Statewide Transportation Improvement Program.

Source: Federal Highway Administration, Highway Safety Improvement Program Manual.

Those threshold values frequently vary by facility type—freeways versus conventional roads, State two-lane versus county two-lane roads, and signalized intersections versus stop-

Figure 4-2. FHWA's Holistic Safety Planning Decision-Making Environment



Source: Federal Highway Administration, Safety Focused Decision-Making Guide.

controlled intersections—and as a result can provide valuable insight into the likely future performance of new facilities.

A newer approach, called "systemic safety" or "proactive safety," addresses severe crashes by widespread deployment of low-cost countermeasures that have been proven to be effective. The first generation of the proactive approach to addressing safety in project development, known as "systematic safety," applied preferred countermeasures to *all* eligible roadways rather than just high-crash frequency locations. That approach may achieve the greatest overall reduction in crashes. Because most agencies are faced with limited resources, it may take years to complete a system-wide implementation of low-cost countermeasures. Instead, the current use of a systemic, or risk-driven, approach identifies locations that have the greatest potential for severe crash reduction and that present the greatest risk for a future severe crash. By focusing implementation on those locations, agencies can most cost-effectively achieve a reduction in the focused-on crash type.

The systemic approach also acknowledges that the risk in some situations or on some roadways is relatively low and may instead merit a lower-cost solution, such as enhanced edge lines, instead of the preferred alternative, such as edge line or shoulder rumble strips. Potential risk is identified on the basis of the presence of risk factors, which are the geometric, traffic, or land use characteristics that are observed to be present in severe crashes. It is important to understand that risk factors are context sensitive, which means they may vary from one facility type to another (rural to urban) or even from one agency to another (county to city). An understanding of roadway and traffic characteristics associated with severe crashes provides planners with an awareness that can also be applied to new roads or alignments, such as the following examples:

- New alignments with a high density of curves would be more at risk for road-departure crashes than ones that are primarily tangential and, therefore, would be candidates for including features associated with proven safety performance, such as enhanced road edges.
- New roads with intersections that have skewed approaches or are located in a curve, or that are both, are more at risk than are intersections with 90 degree approaches located on a tangent. Those intersections would be candidates for including features associated with proven safety performance, such as streetlights and dynamic warning systems.

FHWA encourages agencies to view site analysis and systemic analysis as complementary approaches, using both to their advantage to achieve the greatest number of crash reductions. No single quantitative method is proposed to balance site analysis and systemic investments. However, the nature of the severe crashes within the area—spread across a network versus concentrated at specific locations or corridors—can help agencies determine a desired balance in programming funding.

4.3.2 Application of Substantive Safety Process into Planning and Programming

Integrating substantive safety into any aspect or type of transportation planning (regardless of whether a project is specifically safety driven) can be accomplished by either of the following approaches:

- Incorporate safety-related data to analyze and prioritize with safety tools and methodologies. This approach allows safety analysis to be fully integrated into any other transportation planning process, but it may duplicate the efforts of the safety group.
- Review and reuse safety planning projects, decisions, or priorities (such as project lists, priority strategies, etc.), or a combination of those, during the transportation planning process.

An example of the first approach is analyzing crash data to identify policies, priorities, and projects for an LRTP. That approach allows substantive safety decisions to be fully integrated into the particular transportation planning process underway (whether long-range, transit, freight, etc.). It also allows the safety analyses to be customized to produce the most compatible results with the type of transportation planning underway. However, when an agency already has a dedicated safety group, going through the analysis as part of the transportation planning steps is likely to duplicate the dedicated safety planning process. Furthermore, when conducted separately, the two efforts may result in conflicting decisions, priorities, and projects.

An example of the second approach would be to identify applicable policies and priorities for the long-range transportation plan using the SHSP. Incorporating the projects, decisions, or priorities from dedicated safety planning is more cost-effective, but it may not achieve the desired level of integration. However, that approach can be particularly useful when resources (data or work force) are not available to complete the more detailed analyses. In all likelihood, a combination of the two approaches—at times incorporating data and methodologies, whereas at other times incorporating projects, decisions, or priorities—can achieve a balance between effort and results.

The following paragraphs (using the four steps of the programming and planning phase) highlight examples of how substantive safety can be specifically integrated into the four steps of transportation planning and program development (table 4-4). The examples show the incorporation of approaches and methods, as well as safety planning projects, decisions, or priorities.

4.3.2.1 Purpose and Need Identification

Methods and Tools. FHWA prepared the *Primer on Safety Performance Measures for the Transportation Planning Process* to help "State and local practitioners, transportation planners, and decision-makers identify, select, and use safety performance measures as a part of the transportation planning process."[6] Transportation

planners could also use the same techniques that safety engineers use to develop their plans and programs. Currently, States look to the *Strategic Highway Safety Plans: A Champion's Guidebook to Saving Lives*[7] for information on how to develop their SHSPs. The principles contained in the *Champion's Guidebook* could be applied to the safety element of any transportation plan.

Projects, Decisions, and Priorities. Rather than repeat the same analyses and steps that safety specialists have already taken, transportation planners may simply find the desired information in the results of the safety planning process. The following are examples of safety sources and information that can be used in purpose and need identification:

- Strategic Highway Safety Plan—SHSPs may include information on priority crash types that agencies focus on reducing, crash reduction goals, new or potential policies, and priority strategies for implementation.
- Systemic safety plan—A systemic safety plan may include information on priority crash types that agencies focus on reducing; geometric, traffic, or land use conditions that may increase the potential for a severe crash; and safety projects, including preferred strategies and specific locations.
- Roadway departure, intersection, or pedestrian safety implementation plans—FHWA-assisted focus area plans assist States in developing their own safety implementation plans. The plans provide basic information on the crash issues, guidance on countermeasure types, and priorities for implementation.

4.3.2.2 Data Collection and Analysis

Methods and Tools. As noted, the safety planning process involves project identification, sometimes known as network screening. Data needs and methodologies are documented in several guides used by safety planners. The *Highway Safety Improvement Program Manual* provides an overview of the safety planning analysis process, but specific details on methodologies are available in the HSM and FHWA's *Systemic Safety Project Selection Tool*.[8] Safety Analyst[9] and U.S. Road Assessment Program (usRAP)[10] are two comprehensive software applications that are available to help planners with managing and analyzing the data for road networks. The Interactive Highway Safety Design Model,[11] which incorporates HSM methods, was designed for analyzing corridors and can be used to analyze existing and proposed roadway conditions.

Projects, Decisions, and Priorities. The network-screening step within safety planning is used to evaluate actual safety performance and to identify locations that present an opportunity to improve safety performance. Safety offices, possibly within traffic divisions, maintain a list of those locations, whether determined using the HSM methodologies, the Systemic Safety Project Selection Tool, usRAP, or some other method. The lists are often updated yearly and could be incorporated into transportation plans.

Network Screening Results. Many agencies maintain a list of sites (such as intersections, corridors, interchanges, curves, etc.) that they determined have the potential for improved safety performance. Location lists may simply be in the form of "Top 100" intersections and corridors according to crash frequency or crash rate. They could also be locations identified using HSM methodologies within Safety Analyst. Systemic listings of priority locations may originate from usRAP or the systemic safety analysis methodology.

4.3.2.3 Project Formulation

Methods and Tools. Once data analysis identifies sites of opportunity, the next step of safety planning is identifying potential safety strategies and the preferred option on the basis of performance measures. Safety engineers have access to numerous resources to identify countermeasures, including the National Cooperative Highway Research Program's *Report 500* series: *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan*,[12] *Report 600: Human Factors Guidelines for Road Systems*,[13] and *Report 622: Effectiveness of Behavioral Highway Safety Countermeasures*,[14] as well as the National Highway Traffic Safety Administration's *Countermeasures That Work*.[15] The HSM and the Systemic Safety Project Selection Tool provide direction on selecting strategies to address issues. Crash modification factors are available through FHWA's Crash Modification Factors Clearinghouse.[16]

Another resource that provides information on countermeasures is FHWA's website for proven safety countermeasures (see table 4-5).[17] FHWA summarized "the latest safety research to advance a group of countermeasures that have shown great effectiveness in improving safety." FHWA is encouraging safety practitioners to consider that research-proven set of countermeasures as they are integrated into safety programs on a broader, national basis.

In addition to various guidebooks, references, and resources, software applications such as Safety Analyst and usRAP can help identify potential and preferred alternatives for locations. The programs include a library of countermeasures that can be applied at individual locations. Although the investment in entering sites and corridors into the programs can be extensive, a significant

Table 4-5. Selected Proven Crash Countermeasures

1. Roundabouts
2. Corridor access management
3. Signal backplates with retroreflective borders
4. Longitudinal rumble strips and stripes on 2-lane roads
5. Enhanced delineation and friction for horizontal curves
6. Safety Edge[SM]
7. Medians and pedestrian crossing islands
8. Pedestrian hybrid beacons
9. Road diets

Source: FHWA, Guidance Memorandum on Promoting the Implementation of Proven Safety Countermeasures.

advantage of those programs is their ability to quickly evaluate the effect of several countermeasures.

Projects, Decisions, and Priorities. Transportation planners may find recommended or preferred safety strategies in several sources. Example sources of ready-to-use information include the following:

- SHSP or systemic safety plan—Each document will identify preferred strategies but may vary by the stakeholders that provided input into the plan development. Additionally, an SHSP addresses the greatest needs within the State, whereas the strategies in a systemic safety plan may focus much more on a specific crash type, facility type, or jurisdiction, thereby resulting in some differences in priority strategies.
- Safety Analyst and usRAP—Analysis may have been completed using either software program, with resulting reports that include potential treatments for individual locations.
- Road safety audits (RSAs)—RSAs often address a specific site, corridor, or region. In response to site conditions, the RSA team will identify suggested safety projects and other improvements in the report.

4.3.2.4 Programming and Prioritization

Methods and Tools. Highway and traffic safety engineers and planners have at their disposal several tools that provide direction on prioritizing projects. Fundamentally, the programming and prioritizing of safety projects use crash reductions to estimate the benefit of the strategy or program, contrasted by the project cost. Quantification of the benefits could be made on the basis of total crashes, or it could focus on severe crashes or a specific crash type. The *Highway Safety Improvement Program Manual* and the HSM describe three categories of prioritization methods:

- *Ranking* is the simplest and may be best for making decisions about a limited number of sites.
- *Incremental benefit–cost analysis* compares the economic effectiveness of one project with another, but it does not consider budget constraints.
- *Optimization* is the most complex and is the best method for prioritizing projects on the basis of monetary constraints.

Engineers and planners can also prioritize safety projects according to financial considerations using Safety Analyst and usRAP.

Projects, Decisions, and Priorities. Safety planning, at least at the statewide level performed by State DOTs, results in an HSIP. That program can be incorporated into transportation improvement programs or Statewide Transportation Improvement Programs with no additional work. Other safety plans, including systemic plans, may include project recommendations that can be incorporated into safety programs. Examples of prioritized or programmed safety projects include the following:

- The HSIP project list identifies projects that were considered a priority for Federal safety funds. Local agencies may maintain equivalent examples for their respective jurisdictions.
- A systemic safety plan often includes prioritized project recommendations made on the basis of the analysis process. The projects in a systemic plan, however, may not be programmed projects.
- Both the Safety Analyst and usRAP software programs have the ability to prioritize suggested improvements to provide the greatest return on investment. The information can be system-wide or specific to a corridor or study area. The prioritization results may not be programmed projects.

4.4 TOOLS AND RESOURCES FOR INTEGRATING SAFETY INTO PLANNING AND PROGRAMMING

Agencies can integrate substantive safety into transportation planning and programming by incorporating safety-related data for analysis with safety tools and methodologies. To do so, they must have at their disposal various analytical tools for use in applying those methods. Table 4-6 summarizes the most commonly applied tools for quantitative safety analysis in planning and programming as noted throughout this chapter and provides a snapshot of the current best practices applying substantive safety in planning and programming. The list is not all-inclusive. New tools continue to be developed as the state of practice in substantive safety evolves.

4.5 REFERENCES

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7. Federal Highway Administration, *Strategic Highway Safety Plans: A Champion's Guidebook to Saving Lives*, 2nd ed. (Washington, DC: FHWA, 2013).
8. Federal Highway Administration, *Systemic Safety Project Selection Tool* (Washington, DC: FHWA, 2013).

Table 4-6. Sources for Integrating Safety Planning into the Four Transportation Planning and Programming Steps

	Four Steps of Transportation Planning and Programming			
Tools and Resources	Purpose and Need Identification	Data Collection and Analysis	Project Formulation	Programming and Prioritization
National References				
A Primer on Safety Performance Measures for the Transportation Planning Process	●			
Strategic Highway Safety Plans—A Champion's Guidebook to Saving Lives, 2nd ed.	●			
Highway Safety Improvement Program Manual		●		●
Highway Safety Manual		●	●	●
Crash Modification Factors Clearinghouse			●	●
Systemic Safety Project Selection Tool		●	●	
NCHRP Reports 500, 600, and *622*			●	
Countermeasures That Work			●	
Analysis Tools				
Interactive Highway Safety Design Model		●		●
Enhanced Interchange Safety Analysis Tool (ISATe)		●		●
Safety Analyst		●	●	●
U.S. Roadway Assessment Program (usRAP)		●	●	●
State and Local Safety Analysis or Plans				
State Strategic Highway Safety Plan	●		●	
Systemic safety plan	●		●	●
FHWA focus area: safety implementation plans	●		●	●
Network screening		●		
Road safety audits			●	
Highway Safety improvement Program				●

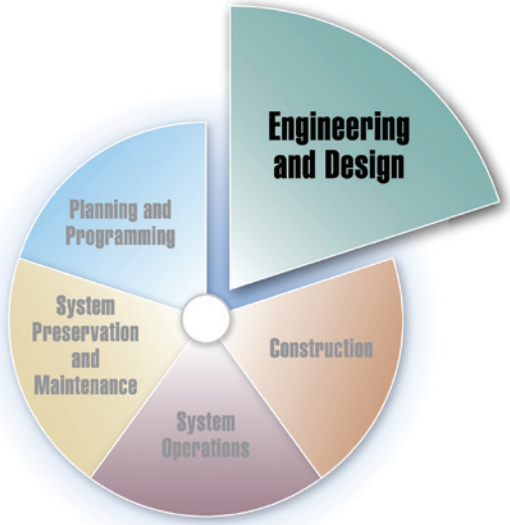
9. American Association of State Highway and Transportation Officials, AASHTOWare, Safety Analyst website, http://www.safetyanalyst.org/.
10. AAA Foundation for Traffic Safety, United States Road Assessment Program (usRAP) website, http://www.usrap.us/home/.
11. Federal Highway Administration, Interactive Highway Safety Design Model (IHSDM) website, http://www.ihsdm.org/wiki/Welcome.
12. National Cooperative Highway Research Program, *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan*, vols. 1–23 (Washington, DC: Transportation Research Board, 2003–2009).
13. National Cooperative Highway Research Program, *NCHRP Report 600: Human Factors Guidelines for Road Systems*, 2nd ed. (Washington, DC: NCHRP, 2012).
14. National Cooperative Highway Research Program. *NCHRP Report 622: Effectiveness of Behavioral Highway Safety Countermeasures* (Washington, DC: NCHRP, 2008).
15. National Highway Traffic Safety Administration, *Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices*, 7th ed. (Washington, DC: NHTSA, 2013).
16. Federal Highway Administration, Crash Modification Factors Clearinghouse website, http://www.cmfclearinghouse.org/.
17. Federal Highway Administration, Proven Safety Countermeasures website, http://safety.fhwa.dot.gov/provencountermeasures/.

ENGINEERING AND DESIGN

5

Photo courtesy of Thinkstock.

Figure 5-1. Engineering and Design in the Project Development Process



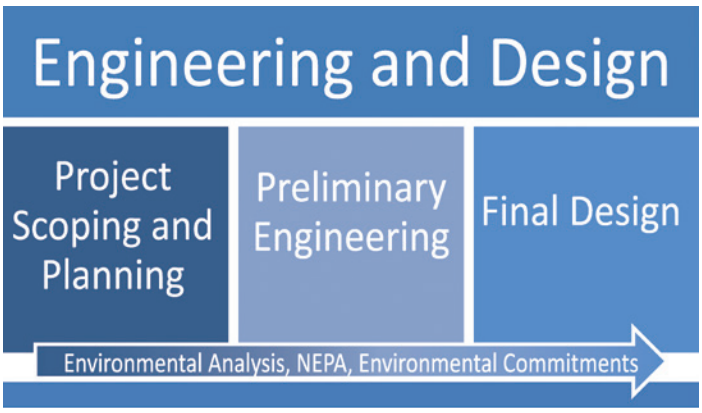
Source: CH2M HILL.

5.1 INTRODUCTION

In the engineering and design phase of project development, a project advances from a concept to a workable design, final plans, specifications, and cost estimate so that the project may be bid for construction (see figure 5-1). Engineering and design deal with the tradeoffs between the extent to which needs are addressed, the project cost, and the impacts on the natural and built environment. The progression from concept to final design includes the development of alternative solutions to address the issues and needs identified during the planning and programming phase.

The engineering and design phase is iterative, and so the steps described in this chapter are not always sequential. More than one possible approach or solution can identify the issues and needs for all projects, regardless of size or complexity. Evaluation of each potential design, and the selection of a preferred solution, involve weighing and balancing the effects, cost, and benefits. The preferred solution will balance

Figure 5-2. Engineering and Design Steps



(a) the implementation cost, (b) maintenance and operating costs, (c) traffic operational performance for all modes, (d) environmental effects, (e) safety performance within the context of the project's consideration of the functional needs of the facility, and (f) the values and priorities of stakeholders and the community.

The need for a project may be directly related to safety or to various other considerations, such as human factors, geometry, operations, asset condition, state of repair, and mobility. In any case, safety will always be a consideration. Each project is unique in its context, challenges, scope, and scale and in the stakeholders involved. As such, it should be developed to include substantive safety considerations throughout project development, including each step of the engineering and design phase.

This chapter has the following objectives:

- Show how to incorporate nominal and substantive safety considerations into the engineering and design phase of project development.
- Provide an overview of the design elements that have the potential to influence safety performance.
- Describe the steps of the engineering and design phase for evaluating safety.
- Provide an overview of tools and resources that can be used to integrate safety into engineering and design.
- Describe how substantive safety evaluation and analysis methods can aid practitioners in making engineering judgments with respect to safety in design.

5.2 OVERVIEW OF ENGINEERING AND DESIGN

During the engineering and design phase, the project advances from a high-level concept to final design. During that process (figure 5-1), a project progresses from alternative identification and evaluation, through preliminary engineering and design, and finally to contract letting and construction. Once a project's need has been identified, alternatives to address that need are developed and then undergo a series of progressively detailed analysis and design steps. Those steps include project scoping, conceptual engineering and alternatives analysis, preliminary engineering, and final design. Throughout that stage, the project proceeds through a parallel environmental stage in which the project is evaluated for impacts on the environment in accordance with an environmental analysis and the requirements of the National Environmental Policy Act (NEPA).

The engineering and design phase has four key steps (figure 5-2):

1. Project scoping/planning
2. Preliminary engineering
3. Final design
4. Safety and the environmental analysis, NEPA process (including environmental commitments in design)

This chapter reviews those primary steps within the engineering and design phase and shows where and how substantive safety can be integrated into engineering and design processes. At the conclusion of this document, case studies are provided that illustrate practical examples of real applications of substantive safety to projects in various stages of engineering and design.

5.3 SUBSTANTIVE SAFETY CONSIDERATIONS

5.3.1 Performance-Based Safety

The design and operation of streets and intersections influence both the number and severity of crashes. Those factors include not only the geometric layout of the roadway but also the traffic control devices and other design features that are included in the project. Careful design can reduce the incidence of human error, the chance of human error resulting in a crash, and the severity of the consequences of crashes when an error does occur. For highway travel to be both safe and operationally efficient, the needs and constraints of highway design, traffic control, and users must be successfully integrated. Highway designers need to know what the effects are of their design decisions and how those decisions will affect traffic control needs and roadway users' abilities to navigate the roadway efficiently and safely.

Acknowledging the quantitative safety differences of design variables in the engineering and design phase allows transportation professionals to make sound engineering judgments regarding performance-based safety. The integration of safety into engineering and design requires that the practitioner understand the relationship between nominal (standards-based) safety and substantive (performance-based) safety. Although many designers understand that adherence to standards alone will not ensure substantive safety, it is often difficult for them to determine how to strike a balance between the requirements of standards and the need to provide and evaluate solutions that have actual safety performance benefits for all users.

The following points may help define the relationship of standards to substantive safety performance; they may also help the practitioner strike a balance between meeting the standards and achieving performance-based (substantive) safety in engineering and design:

- Upgrading to standards should not be considered mandatory. Likewise, not upgrading to current standards should not be considered a deficiency. Nominal safety may be a factor in a design solution. However, to be context sensitive, the design should focus on the substantive safety of the facility.
- The principles of substantive safety—by which the safety performance of the facility and its needs are defined—are the most appropriate for consideration of safety in the evaluation and selection of design criteria. This approach adheres to the American Association of State Highway and Transportation Officials' (AASHTO's) guidance, which allows for flexibility in design.
- An understanding of the design variables with regard to substantive safety can help engineers and designers recognize where a relationship exists between the standards or design criteria and the substantive safety.
- Insight into design elements related to location, terrain, road type, functional class, land use and character, design speed, level of service (LOS), and design vehicles will facilitate engineering judgment with respect to safety within project development.

5.3.2 Integration of Substantive Safety into Engineering and Design

The project development process (PDP) yields detailed, explicit, and more comprehensive quantitative information on costs, rights-of-way, traffic operations, and many environmental consequences. Quantitative information on safety implications and performance was once unavailable. The lack of comparative data reduced the designer's ability to assess safety effects similarly to elements that could be quantified. The advent of quantitative safety data now allows an "apples to apples" comparison of safety with the other key attributes mentioned earlier.

The PDP typically begins at a conceptual level, where the level of detail is limited. That approach makes for an efficient process to consider a wide range of alternatives and design options. As a project advances through design, the level of detail and the accuracy of engineering data and design analysis increase, and the number of alternatives decreases. For example, horizontal and vertical alignments, cross sections, auxiliary lanes, subsurface soil corrections, stormwater drainage, utilities, lighting, pedestrian and bicycle amenities, transit access and operations, and so on are developed in greater detail during the design phase. As that occurs, the level of detail and precision of the safety performance analysis should *increase*. The science of substantive safety, particularly as reflected in AASHTO's *Highway Safety Manual* (HSM),[1] allows for increased precision in the evaluation of either many specific design elements or a single alternative.

Designing to minimum standard values or criteria is an approach that has assumed that adhering to those practices yields a design that addresses safety issues. In reality, nominal safety practices merely address an alternative's adherence to design criteria and standards. Such a factor in itself is not sufficient to guarantee that safety is optimized with regard to the measured crash experience.

Standards-based design values, which are absolute, do not generally reflect the understanding of the incremental differences in safety performance that can be expected as a result of incremental changes in dimensions of any one variable, nor do they consider the safety performance effect resulting from the combination of different elements. Substantive safety varies with changes in traffic volume, roadway elements and features, vehicular speed, land use, and context. The unique context of a facility—that is, the traffic, land use, and special user needs—may lead to unique combinations that increase safety performance that cannot be addressed or analyzed by referencing nominal design standard values.

Safety-conscious design principles and alternatives analysis using substantive safety techniques can be evaluated in the design process using two general approaches. Both involve the explicit evaluation of the safety effects of a given alternative, or the safety effects of the elements that make up the design alternatives.

- **Highway Safety Predictive Methods—**Part C of the HSM provides a good example of the predictive methods that can be used for estimating the crash frequency expected by crash severity and the collision types on a roadway network, facility, or individual site. The estimate can be made for combinations of design elements for various situations: existing conditions, design alternatives, or new roadways. The predictive method allows existing and proposed design concepts and alternatives to be assessed quantitatively in conjunction with capacity, cost, right-of-way, community needs, and environmental considerations.

  The HSM methods basically have a consistent format to provide quantitative estimates, and estimates of what is called "expected crash frequency." The estimation process uses regression models developed from crash data for similar sites. The models start with a base condition that is then adjusted by using crash modification factors (CMFs), according to the safety effects of differing geometric design features, traffic control features, and traffic volumes. Other adjustments are made to compensate for the statistical variance of crash data (such as regression to the mean bias), specific site conditions, and local and regional conditions. (See Part C of the HSM for more details.)
- **Highway Safety CMFs—**Parts C and D of the HSM provide information on the effects of various safety

Figure 5-3. CMF Clearinghouse website

Source: www.cmfclearinghouse.org/.

treatments (countermeasures) or roadway features with regard to their ability to reduce crashes. Additional information relating to CMFs is contained at the Federal Highway Administration's (FHWA's) CMF Clearinghouse website[2] (figure 5-3). A CMF is a quantified estimate of the safety effectiveness of treatments, geometric characteristics, and operational characteristics. The CMFs in Part C pertain directly to the predictive models and should be used for Part C model application. The CMFs in Part D and at the CMF Clearinghouse can be used to estimate the potential crash reduction of a treatment and to convert the crash reduction to a monetary value or a basis for estimation. For example, they can be used for a benefit–cost analysis or other associated impact assessment.

Those two approaches provide the practitioner with flexibility in analysis methods. That flexibility allows the relative complexity of substantive safety analysis to be scaled to meet the needs of the project and available resources. Where data and resources are readily available and project need dictates, a detailed predictive analysis may be the appropriate approach for addressing substantive safety. Conversely, where data are limited or resources are less robust, the simple application of CMFs to evaluate the safety performance may be the more feasible technical approach. Both are considered standard best practices in substantive safety analysis.

The predictive models are not discussed in detail, but the safety relationship of design elements is. That difference clearly illustrates that safety is not constant for a design feature but that safety varies as the design dimension changes. Substantive safety is a continuum, not an absolute. Understanding that basic principle is important in project development, because it allows planners and designers to make better decisions about design in developing alternatives as tradeoffs become apparent.

As shown in table 5-1, substantive safety analysis and tools can be very useful in design because they are widely applicable. Generally, many of the analysis tools will be most effective when applied early in project development because that application facilitates their implementation into a project. The tools are discussed in more detail in section 5.3.4.

Table 5-1. Application of Substantive Safety Analysis and Tools to Engineering and Design

	Engineering and Design Steps		
Analysis Applications/Tools	**Scoping/Planning (includes NEPA)**	**Preliminary Engineering**	**Final Engineering**
Network screening	○	■	●
Diagnosis/crash analysis	○	○	■
Road safety audits	○	○	●
Countermeasure development	○	○	●
Economic analysis	■	○	■
Roadway design context considerations	○	○	○
Design element considerations	■	○	○
Alternative analysis with predictive models	●	○	■
Design exceptions	■	○	○
Value engineering assessment	●	○	○
Constructability and maintenance of traffic	●	■	○

○ *Highly useful and important analysis task*
■ *Moderately important task*
● *Potentially useful task depending on circumstances*

Note: NEPA = National Environmental Policy Act.

Tables A-1 and A-2 (in the appendix) summarize the design elements and variables presented in this chapter, including safety considerations and principles or best practices in safety relative to the design variable. Those summaries give guidance for engineers and designers to use in evaluating safety effects of a particular design element.

The design features and elements that should be part of an overall approach to incorporating substantive or quantitative safety into project development can be grouped into and assigned to the following categories:

- General
- Horizontal alignment
- Vertical alignment
- Cross-sectional elements
    - Lanes
    - Shoulders
    - Medians
    - Roadside
    - Pedestrian and bicycle facilities
    - Intersection design, traffic control, and access management
    - Work zones and maintenance of traffic
    - Intelligent transportation system (ITS)

Crash occurrence, including type and severity, differs significantly between intersections and roadway segments. Road types also have influence over the available performance measures that can be used to quantify safety performance. (For example, lane width contributes to a measurable safety difference on a freeway but not on an urban arterial.) Tables in the appendix group those elements by category—controlling criteria and other key elements—and then by subarea (horizontal, vertical, cross section, intersection, etc.), as noted earlier. General roadway network and freeway and interchange considerations are also included. Discussed later in this chapter are the key substantive safety effects of changes to design features to be considered during project design development.

5.3.3 Safety and the Environmental Process

Safety considerations can arise in many stages of the environmental process. Safety may be the primary inspiration for a project or one of many factors considered during project development decision making. The environmental process runs parallel to and concurrent with the traditional stages of project development during planning, engineering, and preliminary design.

Substantive safety analysis can be particularly beneficial in conducting the early stages of project development, in defining scope and project need, and in identifying and selecting alternatives. That is the point at which agencies proceed with an engineering and environment analysis of each alternative so they can understand the specific costs, effects, and attributes.

Analyses conducted for NEPA frequently assume safety will be maximized solely through adherence to roadway design standards. Addressing this problem requires considering more than standards to maximize the safety of new transportation projects.

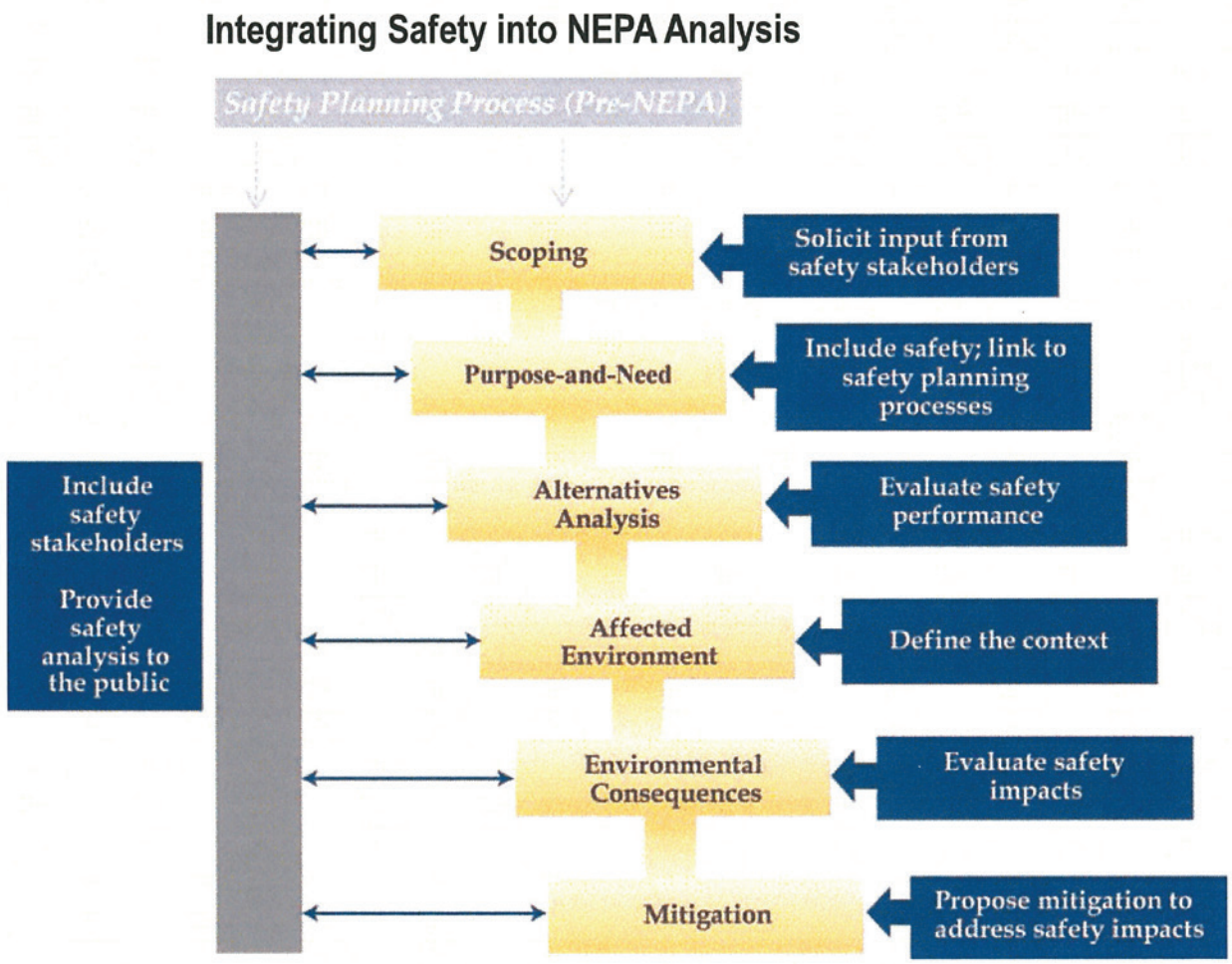
Substantive safety analysis will provide decision makers with objective data to assist in deciding on a preferred alternative to allow the project to move into the design phase. The commitments made during the environmental process must be recorded and addressed in the final design of the project. Follow-through is necessary to ensure that the commitments are honored as the construction work proceeds.

The environmental process that agencies typically use to evaluate the potential effect of proposed transportation projects thus far has assessed project impacts using quantitative tools and methods to estimate measures of noise and air quality, wetlands, threatened and endangered species, and other features important to society. It is now possible to evaluate safety effects in the same way. The knowledge base and methods used to analyze substantive safety can be used to inform and evaluate project decisions and design changes implemented to address impacts on the natural and built environment. Transportation professionals can use proven safety measures as mitigation for safety-focused projects to integrate safety into environmental decision making or to enhance the safety of the roadway because that change can be considered a value-added benefit of every project.

The National Environmental Policy Act requires examination of potential impacts to the social and natural environmental when considering proposed transportation projects involving Federal funds or approval action.[3] NEPA requires examination of potential impacts to the social and natural environment when considering proposed transportation projects involving Federal funds or approval action. The results of safety planning and conventional transportation planning processes may be very useful in NEPA analysis. FHWA's document *Integrating Road Safety into NEPA Analysis*[4] notes that the NEPA process provides a unique opportunity to NEPA and transportation practitioners to improve safety for new transportation projects (see figure 5-4). It states that the development of any new transportation project should do the following:

- Include a safety analysis commensurate with the complexity of the project as part of the review process.
- Use the best available safety data specific to the project location in the review process.
- Involve safety analysis using the best available information and tools.
- Promote dialogue with the general public and key stakeholders about the safety aspects of the project.
- Address potential safety issues associated with construction.

Figure 5-4. Integrating Safety into NEPA Analysis



Source: Federal Highway Administration, Integrating Road Safety into NEPA Analysis, *figure 2.2.*

- Apply innovative educational and enforcement techniques to address such issues as speeding or impaired driving.

It is important to note that the analysis applications of substantive safety to the environmental process and NEPA are not unique or different from those that would be used in the other stages of project engineering and design. Substantive safety analysis can be used in a similar way for any project, regardless of the environmental process required. For projects that require an environmental analysis, the application of quantitative safety to environmental analysis can be woven into project development so that those steps do not fall outside project development but instead are part of the standard process. Local agencies not using Federal funding may have to meet the environmental requirements of their State process.

5.3.4 Application of Substantive Safety to Project Scoping and Planning

A critical time in project development is during the early stages of engineering and design, which is at the point where program planning and project identification transition to preliminary engineering. In that step, constraints and conditions are characterized, and solutions involving a range of infrastructure, operational strategies, and even policies are proposed for study and evaluation in an organized manner with the object being to decide on a solution to implement. It is during that step that the project's purpose and need are refined and finalized, critical success factors are defined, and a scope of work is developed through which alternative solutions can be explored and evaluated.

The design team on every project, not just those with "safety issues," should analyze the safety performance of proposed or alternative solutions. Safety performance may not be the primary driver of the project, but it is important to determine before deciding how the solutions tested may influence safety performance. Project scoping should always include staff members from the agencies responsible for the collection and evaluation of crash and other related data. Project needs related to types of crash data, extent of data, requested analysis support, and so on are discussed and included in the project plan. The need to collect additional data to support analyses may be discussed, with the

objective of ensuring that the desired safety analyses can, in fact, be performed on time and within budget. The following sections detail the applications of substantive safety into the project scoping and planning stage of engineering and design.

The design team on every project, not just those with "safety issues," should analyze the safety performance of proposed or alternative solutions. Safety performance may not be the primary driver of the project, but it is important to determine before making a decision on how the solutions tested may influence safety performance.

5.3.4.1 Network Screening

Network screening is used to identify and rank the locations most likely to benefit from countermeasures to reduce crashes. The sites identified as most likely to benefit from safety countermeasures are then studied in more detail. Various performance measures can be applied across the network. Those measures may also include new facilities or alignments where topographic or other characteristics may necessitate safety-related analyses or considerations. Using that method, the designer can answer this question: how does this location compare with the rest of the system?

5.3.4.2 Project Scoping

Typically, the development process for a given project was initiated as a result of an identified transportation need stemming from congestion or capacity issues, roadway condition, or safety. That process often began without consideration of the context within which the project would be built or without input from the public until well into the project development, if at all. Now, the normal practice for agencies is to include a focus group of the traveling public and the community stakeholders during refinement of the project's purpose and need.

The need for a project can be directly related to the transportation system, or it can come from another area of the community. The initial purpose and need may be developed on the basis of information gathered during the planning and programming phase. However, as a project moves into the engineering and design phase, a better understanding and more detail regarding the needs are often required to define a scope of work from the project-level perspective. It is much more common for stakeholders to help define the issues or needs to be addressed on the project level and to assist in identifying and prioritizing the criteria by which reasonable project alternatives will be evaluated.

Substantive safety analysis is the means by which safety can be evaluated *objectively* and considered when evaluating the effects of various project needs, when adjusting project scope, and when evaluating the effect of differing project alternatives. That substantive analysis enables designers working with stakeholders to address safety issues in meaningful terms and to tailor them to the project's context. Early in project development, safety analysis techniques may include review and statistical evaluation of safety data. Tools such as collision diagrams, condition diagrams, and crash mapping may be employed to flesh out safety issues. As a project develops, predictive safety analysis methods may be used to evaluate and compare alternatives. Quantitative analysis methods allow for a differentiation among potential solutions, an evaluation of "substandard" geometric features with respect to safety, and a clearer definition of safety need in project development.

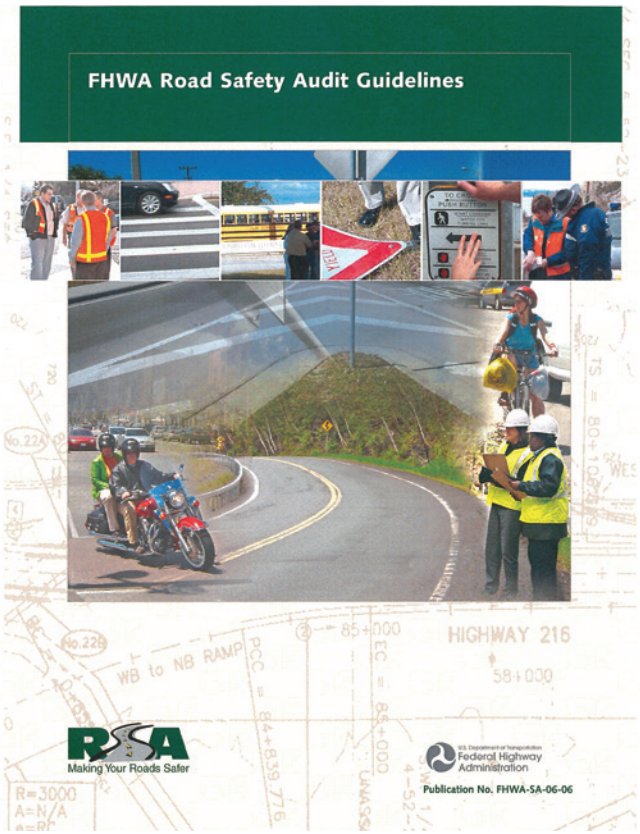
5.3.4.3 Road Safety Audits

A road safety audit (RSA) is a formal safety performance examination of an existing or future road or intersection by an independent, multidisciplined audit team that considers all road users (see figure 5-5).

Diagnosis and evaluation of a project for safety should also include an assessment of field conditions. RSAs are part of a safety-driven process that can be applied at the onset of any project, but they should be included particularly when the identified project needs include safety performance. RSAs are conducted by a multidisciplinary team of design and traffic engineers, maintenance staff, law enforcement, and human factors experts. RSAs build on other road safety improvement strategies and techniques already in use and do not replace them. RSAs can be conducted at any stage within project development. An RSA can be conducted on a segment of roadway focusing on the crashes that have occurred and the potential for crashes. That type of RSA can lead to a project that addresses the issues found during the review. An RSA can be conducted early in project development when the alignments and initial cross-sectional elements are being developed. At that stage, changes can be made without significantly affecting the schedule. An RSA can also be conducted later in project development during detailed and final design, where it tends to focus on more detailed items like traffic control devices and roadside safety hardware. Whenever it is conducted, the RSA should follow a formal procedure consisting of the following steps:

1. Identify project or road in-service to be audited.
2. Select the RSA team.
3. Conduct a pre-audit meeting to review project information.
4. Perform field observations under various conditions.
5. Conduct an audit analysis, and prepare a report of findings.
6. Present the audit findings to the project owner or design team.
7. Prepare formal response by project owner or design team.
8. Incorporate findings into the project when appropriate.

Figure 5-5. FHWA Road Safety Audit Guidelines



FHWA has found that RSA teams have identified safety issues that a traditional safety review would not otherwise have discovered. The RSA team considers the safety of all road users and qualitatively estimates and reports on road safety issues and opportunities for safety improvement. FHWA guidance[5] provides prompt lists for RSAs being conducted during the following stages:

- Preconstruction phase
  - Planning stage
  - Preliminary design stage
  - Detailed design stage
- Construction phase
  - Work zone traffic control plan stage
  - Preopening stage
- Postconstruction phase development projects
  - Land use development

Those prompts assist the RSA team in identifying missing information or existing or proposed characteristics that the project may need to address that may be relevant to the project as the RSA is conducted. The lists can then be used to facilitate the writing of the RSA report. More detailed prompt lists are provided on the FHWA website.[6] However, even the detailed prompt lists cover just the common elements. All team members should use their experience and skill to recognize issues that are to be addressed and that are not on the list.

The written RSA report should contain an explanation of the safety issues identified, the magnitude of the safety issue, and suggestions to address the safety issues identified.

5.3.4.4 Designing for Increased Safety

The safety countermeasures considered for incorporation into a given project should center on the results of the safety analyses done for the project location. During project scoping and planning, a diagnosis of the safety issues should be made to determine the cause of collisions and potential safety issues or crash patterns that can be further evaluated. The countermeasures selected for inclusion in the project should address those identified contributing factors. A number of sources for countermeasures should be considered, such as the NCHRP 500 series of reports,[7] the HSM,[8] and the proven countermeasures published by FHWA.[9] Once countermeasures have been identified, the designer needs to determine which are feasible within the scope of the given project. Once a set of feasible countermeasures has been identified, the predictive quantitative safety analysis can often be applied to evaluate the expected safety benefit of the selected countermeasure.

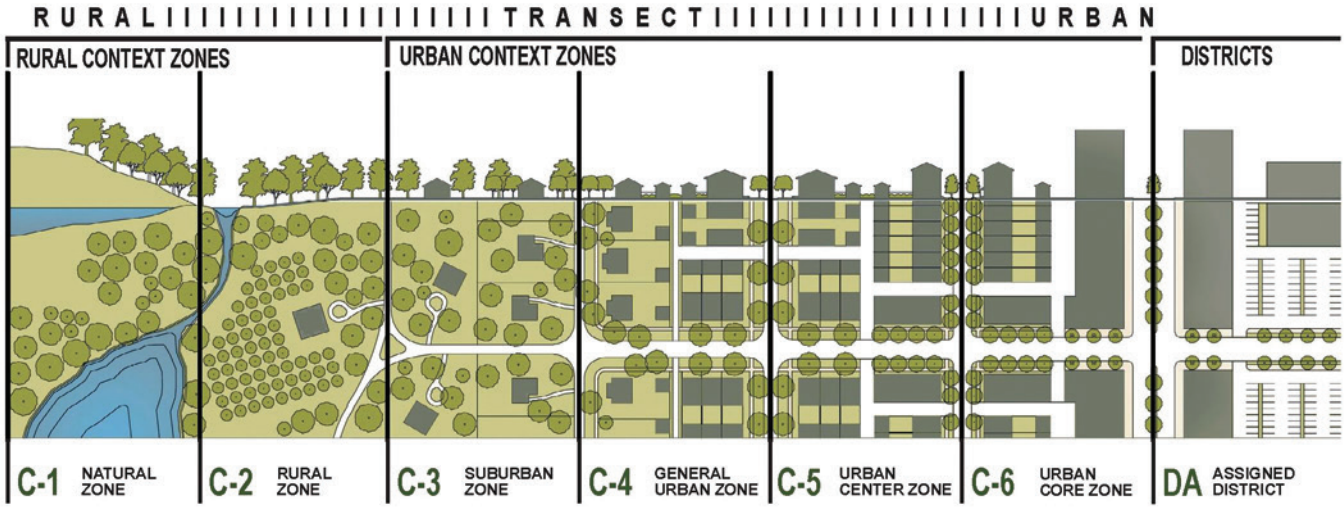
5.3.4.5 Design Controls and Criteria

Establishing design criteria is a critical element in the scoping of any project. Completing the scoping sets the stage for the completion of project development. Design controls and criteria should be defined early in the PDP. The design criteria will direct designers to those solutions that are considered appropriate, which, in turn, will determine the success of the project. Engineering judgment, rather than blanket adherence to standards, should be used to set the criteria appropriate for each project. Designers have choices in their selection of design criteria. In doing so, the project area's context will influence those choices and provide for a successful design.

Land Uses and Character (Context). In *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach*,[10] the concept of context zones (figure 5-6) is introduced, ranging from natural zone (C1) to urban core zone (C6) with assigned districts within the central business district of a city. The use of context zones allows the context to be defined for a specific location. Context zones describe the character of the land surrounding the project—the physical form and character of a place.

From a broader perspective, the concept of context sensitivity and the tailoring of a project design to fit within the environment and community applies to all projects within the transportation project development process. The concept of context sensitive solution (CSS) and context sensitive design (CSD) in project

Figure 5-6. Gradient of Development Patterns Ranging from Rural in C1 to the Most Urban in C6



Source: ©The Urban to Rural Transect Duany Plater-Zyberk and Company.

development is considered best practice, with an expectation that CSS/CSD principles will be applied as an integral part of project development. The context in which a transportation project is to be built sets the stage for defining design controls and criteria. CSD principles and consistency in applying those principles improve the ability of the user to operate and interact safely with other vehicles and modes, thereby minimizing human error and the risk of associated crashes.

Once project context is defined, the design criteria and controls should be identified to establish appropriate project details within the context of the project to be developed. Specifically, the determination of design speed, design LOS and traffic volumes, and design vehicles are all decisions that will influence the operation of the facility. Those determinations should be established so that the operation and expected performance of the project will fit the intended use of the facility and will serve the intended target users.

The chosen design criteria will communicate to the designers what their approaches should be in developing solutions. They will also communicate to other stakeholders the agency's expectations regarding the roadway and its intended functions. CSS involves bringing stakeholders into project development early, when the needs of the project are being defined. The stakeholders' input should help guide designers in setting the criteria for the project and in making decisions on tradeoffs as the design progresses.

The known relationship between safety and design features must be considered when selecting design speed. Design speed is used to determine the various geometric design features; as a result, it creates the basis for the three-dimensional footprint of the road. Design has many aspects, such as roadway curvature, lane width, intersection elements, and roadside design, that are influenced by design speed.

Many considerations can come into play when balancing mobility and safety with respect to speed. In *Designing Walkable Urban Thoroughfares*, the concept of target speed is introduced.

> Target speed *is the highest speed at which vehicles should operate on a thoroughfare in a specific context, consistent with the level of multimodal activity generated by adjacent land uses to provide both mobility for motor vehicles and a safe environment for pedestrians and bicyclists. The target speed is designed to become the posted speed limit.*[11]

For optimal safety performance, the decision on the design speed should support the roadway context and should consider the effects on safety performance as a result of changes in design elements. That often means setting the design speed equal to the target speed to encourage operating speeds at or below the target speed. Where the location, road type, and context emphasize vehicular mobility, a higher design speed may be appropriate. Conversely, where the context suggests the presence of pedestrians and other vulnerable road users, lower design speeds are appropriate.

Design Level of Service or Target Operating Thresholds. The quality of traffic service provided by specific highway facilities under specific traffic demands is defined by LOS. The *Highway Capacity Manual*[12] does not require roadways to be designed for a given LOS. The choice of LOS is left to the designer or agency. Although highway agencies strive to provide the best practical LOS, often the emphasis is on optimizing operations through maximizing throughput and minimizing delays. Levels of service are also established for broad-based implementation across an agency's system and therefore do not consider the effects on safety performance or the specific context

of the roadway, as they are directly related to a project. However, it is possible that the optimal condition for operations may not align exactly with the optimal conditions for safety performance. Therefore, the design LOS for a project should always be evaluated for reasonableness in the specific project area context.

The 2010 edition of the HCM incorporates a multimodal LOS methodology that can be used to evaluate tradeoffs among the various modes of travel on urban streets. Those multimodal performance measures focus on the quality and convenience of the facilities as well as the traffic flow. For optimal safety performance, the design should fit the context of the roadway and should also consider implications of traffic operations on safety.

When selecting a target LOS, it is important to consider the relationship between speed and operations. Higher speeds are known to increase crash severity. It is also known that crash risk increases with increases in speed differential between vehicles in the same traffic stream or between adjoining sections. An agency may set targets for maximized operations without regard to the safety effects on the surrounding network as a whole. For example, although improving the LOS on a priority corridor to meet a set target will increase throughput, it will also lead to increased operating speed and may compromise operations on connecting streets. Lower LOS thresholds—or an approach that considers not only the maximization of flow on a primary route but also the effects to flow on the connecting routes—can encourage lower operating speeds on the primary route and can also provide for more consistent speed flow and operations on the connecting street system.

Design and Control Vehicle. Design vehicles are used to develop details of intersection design, pavement markings, and channelization. Designers have a wide range of design vehicles for potential use. However, there are tradeoffs to consider in selecting the design vehicle. Intersections designed for large semitrailers will require more space, larger turning radii, and generally greater pavement areas. In locations or context zones where pedestrians prevail, the same design may reduce the border area for nonvehicle uses and increase pedestrian exposure to vehicles and potential collisions.

Where regular accommodation of the design vehicle type is expected, particularly for turns at an intersection with high volumes of opposing traffic, application of the design vehicle concept is appropriate to ensure limited encroachment into the opposing traffic lanes. However, where infrequent use of a facility by the design vehicle is expected, the ITE report *Designing Walkable Urban Thoroughfares* recommends consideration of a control vehicle to set design parameters for the transportation facility. Coupling substantive safety performance with that concept of a control vehicle will allow the designer flexibility in selecting a "design" vehicle that fits the context of the facility with a full understanding of the safety performance of the proposed design.

5.3.5 Relationship between Design Features and Substantive Safety

The traditional process for project development relies on the application of design standards and criteria for the three dimensions of the roadway: cross section, horizontal alignment, and vertical alignment. Project design criteria are generally based on AASHTO's *A Policy on Geometric Design of Highways and Streets*[13] and on companion documents, such as *A Policy on Design Standards: Interstate System*[14] and *Roadside Design Guide*.[15] Depending on the project, local and State guidance may also apply. The presumption by most is that those criteria are related directly to safety, but that is not always the case. For example, AASHTO's basis for horizontal curves is driver comfort and is not related directly to any data-driven studies of substantive safety. The basis for stopping sight distance and vertical curves is not crash data research but rather the exercise of a simple model (driver seeing an object in the road and braking to a stop) with research conducted to determine the model's parameters.

Understanding substantive safety and the benefit of evaluating project design with regard to a data-driven, quantifiable safety approach requires knowledge of the relationships among driver actions, the environment, traffic, and other characteristics and of the effect those relationships can have on crash frequency and severity (injuries and fatalities). Yet most design criteria (horizontal and vertical alignment, lane and shoulder widths) were established years ago without knowledge about the effects of geometry on crashes. Some criteria, such as roadside design, have been refined over the years to incorporate crash experience or risk analysis. Until the recent acknowledgment of the research and knowledge on substantive safety covered in the HSM, advancement beyond those limited applications has been difficult. With the knowledge now available on substantive safety, that approach is changing.

The standards and criteria normally used in designing roadway facilities were generally developed without explicit consideration of the substantive safety effects of changes to the associated design element. Many roadway features affect the substantive safety of the facility. The following sections present examples of substantive safety in design elements, including the applicable controlling criteria noted, in addition to other prominent design and operational decisions. For more detail on the design elements associated with substantive safety principles and their respective effects on safety, see the tables about safety considerations in the appendix.

Sight Distance. Sight distance encompasses several dimensions where design is concerned. For design, four types of sight distance are typically considered: stopping sight distance, decision sight distance, passing sight distance, and intersection site distance.

It is important for the transportation professional to understand the relationships between those values and how they are used in establishing design standards. Stopping

sight distance must be provided along the entire route, and the FHWA considers it a primary controlling criterion for roadway design. Because decision sight distance gives drivers an additional margin for error and affords them more time to make appropriate decisions, it is considerably longer than stopping sight distance. Decision sight distance is not a required criterion, but it is desirable wherever drivers will encounter conditions that make the driving task more complex, like approaching unusual intersections or merge areas.

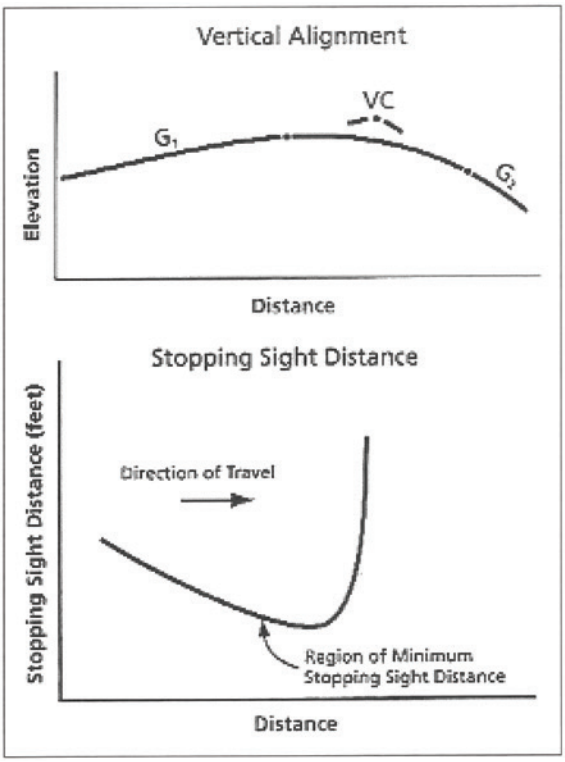
The safety effects of shorter sight distance are greater if the part of the route that cannot be seen also has an intersection, hidden driveway, tight curve, or other unexpected feature to which a driver must react. A sight distance profile is a useful tool for evaluating the effect of reduced stopping sight distance on safety. An example stopping sight distance profile is shown in figure 5-7. Stopping sight distance profiles illustrate the amount of sight distance available at each location and help designers evaluate the effect on safety from a sight-restricted location. Curves in particular greatly influence driver behavior and speed. Tight horizontal curves with obstructions inside the curve affect both stopping and decision sight distances.

Horizontal Alignment. Superelevation along with horizontal curvature has a significant effect on off-road crashes. The friction factor of the pavement also affects off-road crashes. In general, flatter curves tend to be safer. However, the designer must be aware that with the same deflection angle, the flatter curve will be longer. Moreover, all those factors have a greater effect when there is a high percentage of heavy vehicles with a high center of gravity.

High-speed routes require superelevation on the curves that provide driver comfort and the ability to control the vehicle. Tight curves on routes with a high percentage of large vehicles may need to have the lanes widened through the curves to accommodate the off-tracking of large vehicles. The proper design of lanes on curves decreases the frequency of crashes attributable to vehicles unable to stay within their lanes. In urban areas, superelevation is not used as much because of lower speeds and more closely spaced driveways and intersections. Horizontal alignments are designed to provide an offset that will allow sight distance through the inside of the curve. Consistency in the design is important to avoid violating the driver's expectancy. Tight curves after long tangents tend to lead to expectancy violations resulting in lane-departure crashes.

Vertical Alignment. There are criteria thresholds for minimum and maximum grades. The minimum grade is specified to ensure that water will drain off the pavement surface. Proper drainage improves safety by reducing the likelihood of vehicles hydroplaning or being unable to stop because of ice on the pavement. Maximum grades depend on the function of the road. Long, steep grades reduce the speed of heavy vehicles to a crawl. Trucks at very low speeds may lead drivers of faster vehicles to attempt passing maneuvers at undesirable locations. Climbing lanes should be considered on extended steep grades.

Figure 5-7. Stopping Sight Distance Profile



Source: American Association of State Highway and Transportation Officials, Highway Safety Manual.

Cross Section. The surrounding land use, whether urban or rural, will have a significant effect on the design. The different types of users will influence the types of components that are required in the typical sections for the project. Shoulders are acceptable for pedestrians or bikes in suburban or rural areas under some conditions. If planners are to provide for higher volumes of pedestrians, sidewalks or sidepaths will be needed. For bicycles, shared-use pathways or bike lanes may be required. Where there is high-speed traffic, a separation or barrier may be needed between the pedestrian facility and the travel lanes.

Traffic studies typically determine the number of travel lanes to be provided for the vehicle traffic on roadway segments and at intersections. The LOS to be designed for varies with the context of the project. In large urban areas, there is more tolerance for congestion than in rural or small urban areas, so the design LOS may be lower. In rural areas, projects are usually designed to operate at LOS B or C. In urban areas, the design LOS is usually C or D, but it can be even lower, depending on traffic demand and available right-of-way. In urban environments, the cost of right-of-way is usually much higher, making it more expensive to add lanes.

The distribution of the traffic throughout day and traffic growth projected during the design life of the project will have a direct bearing on the number of lanes to be provided. In some cases, an increase in traffic volume is to be discouraged, so the project will

intentionally not provide increased capacity and may instead focus on mobility enhancements, such as signal timing and coordination to mitigate congested conditions. However, at all times, the designer should be aware that the level of congestion could have a significant influence on the frequency of multiple-vehicle crashes.

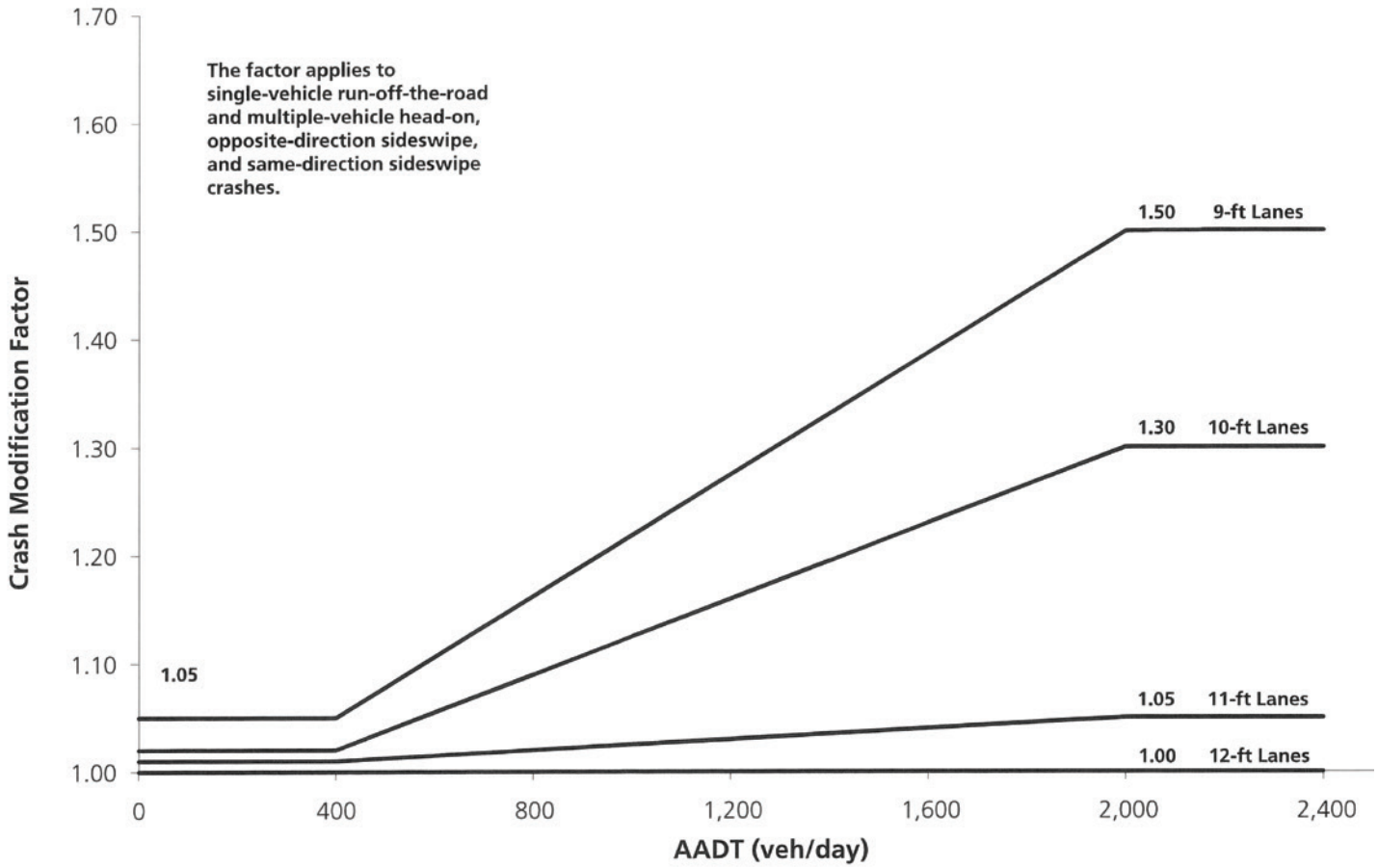
The vehicle mix, nonvehicular users, and design speed are the important factors in determining the type of lanes provided, the lane widths, and the shoulder type and width. The combination of the horizontal and vertical alignment and the lane and shoulder widths is a major factor in the likelihood of road-departure crashes. Access control and type of intersection control are factors in the decision on where to provide left- or right-turn lanes.

The following are additional substantive safety considerations for use in incorporating safety into preliminary engineering for key cross-sectional design elements. Tables A-1 and A-2 contain additional information on those and other cross-sectional elements, including safety effects.

- **Number of Lanes**—The number of lanes needed for a roadway is decided primarily on the volume and composition of traffic. Usually, the focus is on the number of travel lanes, a primary factor used to determine the capacity of the roadway. In urban areas, an additional lane may be used for parking, transit, or bicycle travel. The provision of an adequate number of lanes that give the expected LOS will reduce congestion and interactions and conflicts between vehicles.

  As congestion becomes more severe, sideswipe crashes may increase from an inability to change lanes. Drivers have a greater tendency to follow closely in those conditions, resulting in more rear-end crashes. Adding lanes can help reduce congestion-related crashes, but it may have the opposite effect for pedestrian crashes along urban and suburban arterials. Research has demonstrated that the greater the number of lanes to be crossed by a pedestrian in a crosswalk, the greater the risk for a vehicle–pedestrian crash. So adding travel lanes in areas with high pedestrian traffic may have an adverse effect on pedestrians and needs to be carefully considered.
- **Lane Types** (conventional, transit-only, high-occupancy vehicle, bicycle)—Where there is heavy use by specialized users, special-purpose lanes may be desirable. Providing bike lanes or wide curb lanes encourages their use and makes travel by bicycle safer and more comfortable. Transit-only lanes help buses move through traffic without interference from passenger cars and provide more reliable service. Providing lanes for specialized users reduces conflicts between vehicles, decreasing crashes that result from those conflicts.
- **Lane Width**—Lane width needs to be considered along with the other items within the roadway cross section, such as shoulders and medians. It is also important to understand the roadway type and context of the roadway when determining appropriate lane widths.
  - The width of the lane is known to influence driver comfort and possibly the speed a driver selects. High-speed arterials and freeway facilities generally use 12-foot-wide lanes. Single-lane interchange ramps or turning roadways are usually wider, say 15 to 16 feet. It is also common practice to widen lanes on tight horizontal curves regardless of roadway type, and where trucks operate on very tight curves, lanes should be widened to accommodate off-tracking. In these contexts, wider lanes help drivers keep their vehicles within the lanes, reducing all crash types that result from lane departure such as sideswipe, head-on, off-road, and fixed object crashes. Figure 5-8 shows the relationship between crashes and lane width for a two-lane rural road.
  - In urban areas where speeds are lower, right-of-way is tighter, and the percentage of trucks is low, 11- or 10-foot-wide lanes are more common. Wider outside lanes can be provided where bicycles are common, but bike lanes are not provided. However, wider lanes increase the crossing time and distance for pedestrians in a crosswalk. In urban situations, narrower lanes can encourage slower speeds, reducing the severity of crashes for vehicles as well as pedestrians and regardless of location, narrower lanes are beneficial for pedestrians crossing the street, since the crossing distance and time are less.
- **Shoulders** (presence and type)—When provided, shoulders create an area for stopped vehicles and emergency vehicles and, in some cases, accommodate bicycle use. Shoulders have been shown to have a safety benefit on high-speed highways. Shoulders provide a place for disabled vehicles out of the travel lane. Shoulders provide space to allow a vehicle to leave the lane to avoid hitting an object in the lane. They also provide additional lateral offset to any fixed object and make it more likely that an errant vehicle will be able to return to the road reducing the frequency of off-road crashes. In terms of safety performance, a reduction in crash frequency can be associated with increasing the shoulder width. The safety performance of a roadway can be influenced not only by the width of the shoulder but also by the type. Type considerations include whether the shoulder is paved, gravel, turf, or a composite of pavement and turf. The criteria for a facility may require paved shoulders. On low-volume roadways, shoulders may be usable without being paved. Paved conditions produce the best safety performance.
- **Shoulder Width**—Shoulders provide space for several functions, such as emergency storage of disabled vehicles, enforcement activities, maintenance activities, or additional maneuvering room to avoid a crash. Shoulders help to provide more sight distance on tight horizontal curves, giving drivers more time to react to unexpected situations.

Figure 5-8. Crash Modification Factor for Lane Width on Two-Lane Rural Roads



Source: American Association of State Highway and Transportation Officials, Highway Safety Manual.

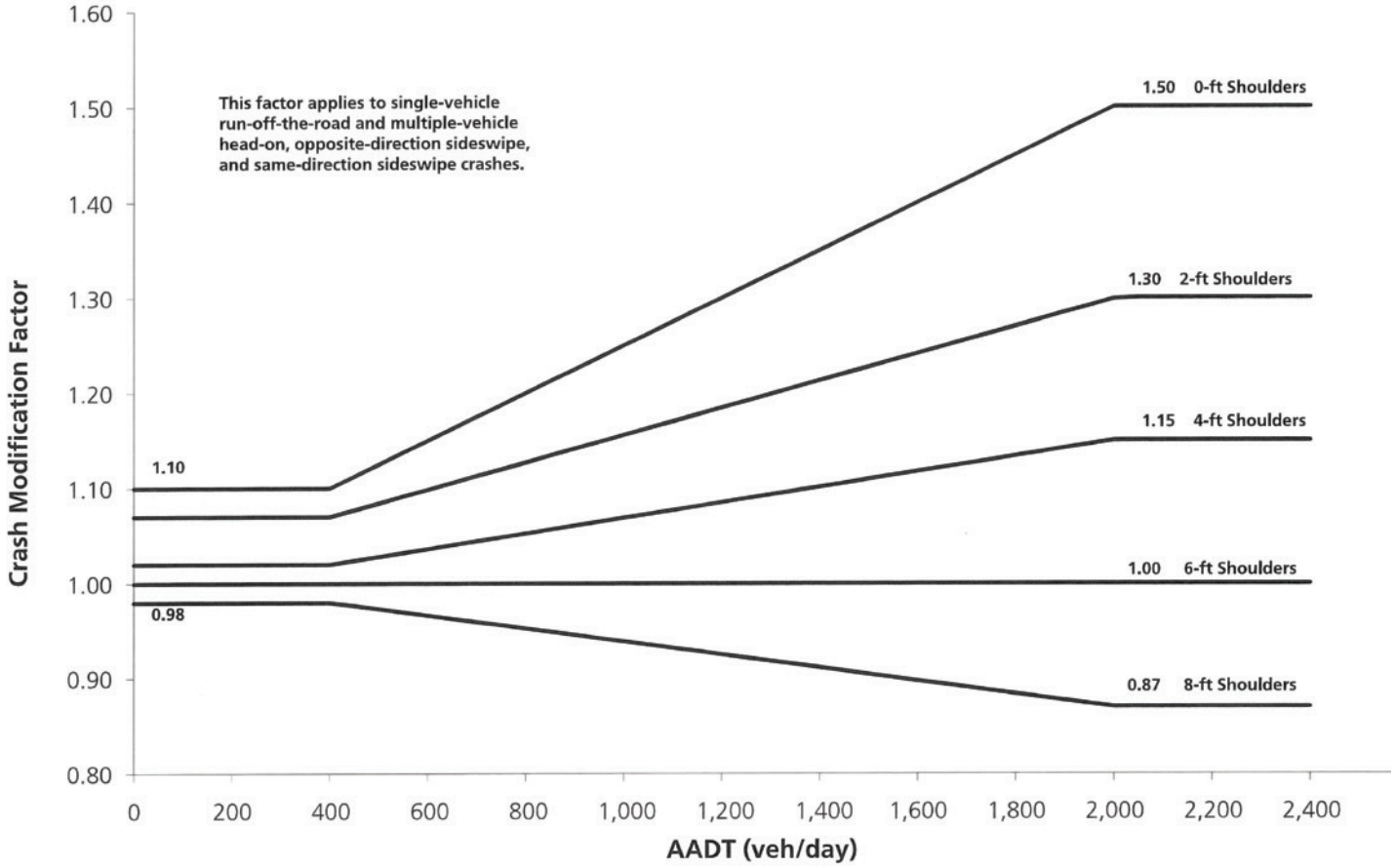
Pedestrians can use shoulders when sidewalks are not provided. Bicyclists can use shoulders as well. In high-volume situations, shoulders add to driver comfort, so they may help increase the capacity of the adjacent lane. Driver comfort may be achieved with 6-foot-wide shoulders. Shoulder width of at least 8 feet is needed to allow vehicles to get completely out of the travel lane.

However, 10-foot-wide shoulders are required for interstate mainline facilities. Where the volume of trucks is greater than 250 per hour, 12-foot-wide shoulders are recommended. As traffic volumes increase, the effect of shoulder width makes a bigger difference for safety. The presence of full paved shoulders that allow drivers to recover and return to the travel lane contributes to the safety through curves.

Part C of the HSM has the CMFs for rural two-lane facilities. (For background information on CMFs, see *Highway Safety Manual* in section 5.3.2.) For rural two lane roads, the base condition referenced in the analysis is a 6-foot-wide paved shoulder. The CMF for a base condition is always 1.0. The CMF for shoulder width, assuming a paved shoulder ranges from 1.5 for no shoulders to 0.87 for shoulders equal to or greater than 8 feet. See figure 5-9 for shoulder examples. Figure 5-10 illustrates the relationship of the CMF values for shoulder width on two-lane rural roads.

Figure 5-9. Rural Two-Lane Highway and Urban Freeway, Each with Full Shoulders

Figure 5-10. Crash Modification Factor for Shoulder Width on Two-Lane Rural Roads



Source: American Association of State Highway and Transportation Officials, Highway Safety Manual.

- **Roadside Clear Zone and Lateral Offset to Obstruction**—The lateral offset is the distance from the edge of the traveled way to an obstruction, such as a utility pole, light pole, bridge pier, or sign structure on the roadside. For safety, the lateral offset should be great enough that the fixed object does not affect the driver's speed or position in the lane. Lateral offset is not a clear zone, but a clear zone should also be considered.

  A clear zone is an area that is adjacent to the traveled way, that is free of obstructions and is traversable, and that allows an errant driver to safely return the vehicle to the roadway after departing from the travel lane. Traversable side slopes are free of fixed objects and are flat enough that a vehicle will not overturn and can be driven back into the travel lane. The width of the clear zone should be determined by the speed and traffic volume on the roadway, as well as by the side slopes adjacent to the traveled way
- **Medians and Median Types**—Medians separate traffic flowing in opposite directions and provide an area for left-turn lanes that allow for speed change and removal of turning vehicles from the through lane. The width of a median varies widely, depending on the type of facility. In urban areas, medians can be as narrow as 4 feet plus the required left-turn lane width. In rural areas, the median may also serve as an area for stopping in an emergency and for facilitating drainage. Providing a median separates opposing traffic flows, thus reducing the incidence of head-on crashes. Medians wide enough to allow left-turn lanes to be cut in maintain the alignment for through traffic, thereby reducing crashes resulting from lane departures. Medians can help with access control by reducing the number of opportunities for left turns through opposing traffic.
- **Cross Slope**—The cross slope drains the water from the roadway. Removing the water from the pavement helps with maintenance and reduces the formation of ice on the pavement. Both maximum and minimum criteria are set for the cross slope. The cross slope should be steep enough to drain the water from the pavement but not so steep as to cause drift to the side or a transverse slide in snowy or icy conditions. The cross slope should not be so great as to cause heavy vehicles with high centers of gravity to lose control when crossing the crown to change lanes. In superelevated sections, the break between the superelevated lane and the shoulder cross slope should not exceed 8 percent. The designer should

pay attention to the combination of longitudinal grade and cross slope to ensure that there are no flat sections.

- **On-Street Parking**—On-street parking helps businesses that do not have land available for off-street parking lots. Parking maneuvers affect the capacity and safety of the adjacent travel lanes. Providing on-street parking tends to increase conflicts between through traffic and vehicles attempting to park, which leads to increased crashes. Parking is normally provided only on low-speed streets, where crashes would tend to be of low severity. Parking can have a traffic-calming effect by reducing speeds, and it also signals to drivers that they are entering an urban area and should slow down. On-street parking also provides a buffer between moving traffic and pedestrians. But parking at intersections may reduce sight lines and lead to more angle crashes. Parking can obstruct the view of pedestrians, thereby reducing driver awareness and increasing the risk of a pedestrian crash. Even at low speeds, angle and pedestrian crashes can be severe.
- **Pedestrian Facilities**—Sidewalks are needed for pedestrian safety and mobility. To be effective, pedestrian facilities need to be continuous. A successful transit system requires sidewalks that connect transit stops and destinations. Pedestrians are extremely vulnerable road users, and crashes with vehicles predominantly result in injuries to the pedestrians. Pedestrian facilities help reduce such crashes when the facilities are continuous. Crosswalks must be provided in logical places to make sidewalks safe and useful.
- **Bicycle Facilities**—On urban bike routes, on-road bike lanes are usually provided. On higher-speed rural routes with significant volumes of bicycles, a path separated from the road is usually included within the right-of-way. On rural routes with a low volume of bicycles, such bikes are usually accommodated on a paved shoulder. Because crashes involving a vehicle and a bicycle are often severe, the provision of bicycle facilities offers a significant safety benefit.

Intersections. Intersections are the most complex areas in the roadway network, and users are the major factors in the design of intersections. Intersections are designed to accommodate the crossing paths of the different streams of traffic flowing through in different directions. In addition to conflicts between vehicles traveling in different directions, intersections are the main source of conflicts between the more vulnerable users and vehicles. Pedestrians use crosswalks to cross the paths of the vehicles. Bike lanes have a crossing conflict with right-turning vehicles. Balances must be struck between the provisions for the various users. For example, shorter crossing distances provide safer conditions for pedestrians. More open space and a wider crossing might accommodate the off-tracking of large vehicles, which can help reduce vehicular conflicts.

The intersection is designed according to the function of the routes, as well as the speed and volume of existing traffic and of that projected for the design year. Many intersections with lower volumes operate with stop sign controls. Those basic intersections rely on having enough sight distance and driver's judgment to determine when there is an acceptable gap to turn onto or cross the route. As volumes increase and the number of gaps decreases, drivers tend to accept shorter gaps, which lead to safety issues.

Traffic signal or roundabout controls can accommodate higher traffic volumes. Roundabouts are appropriate where the through traffic can be slowed, and the traffic distribution will provide the gaps to allow all approaches to operate with acceptable delay. Roundabouts improve safety by reducing the number and severity of conflicts. Traffic signals can provide a safety benefit for pedestrians. The following are additional substantive safety considerations for incorporation into preliminary engineering for key intersection design elements. Tables A-1 and A-2 contain additional information about those and other cross-sectional elements as well as safety effects.

- **Intersection Types**—Intersections have a great influence on safety. The location, spacing, and design of intersections are critical to the operation and safety of any route. Most conflicts occur at intersections, which is where different travel paths cross. Types and sizes of intersections vary considerably, according to the route type and traffic volume. The type of traffic control has a major influence on safety and on the geometric design of the intersection. The geometric layout and type of traffic control at an intersection should be considered to fit in the context of the surrounding area and to meet the needs of all types of users.

  Provision of turn lanes and channelization for the various movements can help separate the conflicts that lead to crashes. Roundabouts are designed to slow traffic and to reduce the number and severity of conflicts and any resulting crashes. Traffic signal control separates conflicts by time, allowing only nonconflicting movements at any given time. Traffic signals rely on drivers to obey the signal indication. Running through red lights can result in severe crashes. Stop sign control relies on the driver's selecting an appropriate gap in the traffic stream.
- **Intersection Turn Lanes and Channelization** (corner radii)—Auxiliary lanes at intersections help increase the capacity for the given movement and reduce the effect that the turning traffic has on through traffic. Turn lanes also provide for deceleration and storage of turning vehicles out of the path of through traffic, thus reducing the likelihood of rear-end crashes. Large corner radii help large trucks maneuver more easily on right turns, but those radii also increase the crossing distance for pedestrians. Larger turning radii may increase the speed of the turn maneuver, which will make it more efficient for the turning vehicles, will result in

less off-tracking by large combination vehicles, will allow those large vehicles to stay in their lanes, and will reduce the likelihood of collision with other vehicles. However, increasing the speed of automobiles will adversely affect pedestrian movements.

Access Management. The primary function of local streets is to provide access. Access control is desired for safety on high-speed, high-volume arterials. Any access point involves some conflict between the through traffic and the entering and exiting traffic and potentially involves additional conflict points with pedestrians and bicyclists. Too many access points tend to create safety issues for high-speed or high-volume through traffic. The degree of access control needs to be consistent with the function of the road. Increasing the number of access points per mile also increases the expected number of crashes. Depending on the density of access points in rural areas, a significant reduction in the density of access points can result in crash reductions of up to 30 percent. On urban and suburban arterials, reducing the number of access points is expected also to reduce the number of crashes, but the extent is unknown. However, limiting access to businesses may adversely affect their commercial viability.

5.3.6 Human Factors

Research has found that specific elements of roadway design can influence human behavior by affecting a driver's visual demand and ability to react. Specific elements include sight distance requirements; sign design, placement, and spacing criteria; dimensions for road markings; color specifications; sign letter fonts and icons; and even components of vertical and horizontal curve design.[16] Drivers make mistakes because of human physical, perceptual, and cognitive limitations. Although such errors may not result in crashes—because drivers compensate for other drivers' errors, or because conditions are forgiving and allow the driver to maneuver to avoid a crash—driver error is still a significant contributing factor in most crashes. Misperceptions, slow reactions, and poor decisions are the products of a poor match between the needs and capabilities of drivers and the task demands that they face on the roadway.

Roadway design considerations for reducing driver workload include the presentation of information in a consistent manner; that is, the design presents information sequentially rather than all at once for control, guidance, and navigation. A roadway environment should be designed in accordance with driver expectation. Drivers are more likely to make errors, potentially resulting in crashes, when their expectations are not met. When drivers can rely on past experience, they have less to process. And that experience reduces demand on their attention and allows them to focus on processing only the new information, thereby lessening the chance for driver error.

> **The form of highways, streets, interchanges, and intersections has a direct impact on performance measures beyond average delay or travel time for an automobile.… Our streets and highways directly influence the quality and substance of how we live.**
>
> ***—Report 785: Performance-Based Analysis of Geometric Design of Highways and Streets***

5.3.7 Application of Substantive Safety in Preliminary Engineering

Once a preferred concept is selected, that concept is taken through preliminary engineering and analysis. A preferred project alternative is selected and advanced to final design. Typical decisions by the design team during preliminary engineering and alternative analysis include the following:

- **Access vs. Mobility**—Access and mobility are competing needs. No single route can provide the maximum of both. Having numerous access points also means having numerous conflicts between the through traffic and the entering or exiting vehicles. Limiting access increases safety and efficiency for through traffic.
- **Pedestrian vs. Motor Vehicles**—Features that increase efficiency for motor vehicles can make travel harder for pedestrians. Turn lanes and large turning radii that reduce conflicts between motor vehicles and that make turning movements faster and easier for motor vehicles also make crossing times and distances greater for pedestrians in crosswalks. Although wide arterials may provide refuge for pedestrians in the median, the resulting two-stage crossing for pedestrians adds delay.
- **Bike lanes vs. Parking Lanes**—Providing on-street parking may be good for area businesses and help the economy of the central business district. However, it can have an adverse safety effect on bicyclists. Bicycles usually travel between the parked cars and the vehicles in the travel lanes. Cars making parking maneuvers conflict with bicycle travel. Drivers' opening the doors of parked cars is another source of conflict between the parked vehicles and bicycles.
- **Commuters vs. Freight Haulers and Truck Drivers**—Providing an additional lane while narrowing all the lanes can add capacity for passenger cars but can make maneuvering more difficult for large trucks.
- **Private Vehicles vs. Transit Vehicles**—Providing a separate lane for buses or high-occupancy vehicles may mean having one fewer general-purpose lane. Providing bus pullouts may help reduce delay and the potential for rear-end crashes for passing traffic, but pullouts may increase the delay for buses

that are trying to merge into the traffic stream after dropping off or picking up passengers.

- **Through Traffic vs. Local Access and Circulation**—Alternatives may need to address the competing interests of providing for higher-speed, uninterrupted traffic flow through the project area and providing access to and travel between local destinations within the project area. Those competing interests require differing approaches to number of lanes, lane width, and speed for the through traffic versus other design conditions such as intersections, access points, bike lanes, pedestrian facilities, medians for refuge, and parking for local users and access.
- **Safety vs. Other Needs**—Safety is often not the primary purpose of or need for a project, but safety should still be considered as part of any alternative development, evaluation, and selection. Although a "safe" facility is often unstated as a need, the traveling public expects the highway agency to provide one. Quantitative safety analysis of proposed alternatives can identify opportunities for safety mitigation strategies to offset any safety effects associated with the alternative design.

During preliminary engineering, the pavement design and typical sections are decided. Horizontal and vertical alignments are refined. Concept bridge and retaining wall studies are conducted. The preliminary plans are developed to a sufficient level of detail to determine the needed right-of-way. The plat is prepared at that time, so the right-of-way can be purchased. Putting all the various elements together forms the basis of the final design.

Utility coordination is also important during the preliminary engineering step. Keeping the roadside area free of fixed objects, including utility equipment, helps improve safety. Ideally, the design can be refined to reduce utility impacts. If required, utility relocations can be accomplished before construction of the roadway improvement. When designers locate utility facilities within the right-of-way, they should consider the fixed object that could be hit. Also, measures should be taken to provide for the safety of the utility workers who will maintain those facilities. Preliminary cost estimates are prepared to track budgets, to make certain the funding is in place to purchase the required right-of-way and relocate any compensable utility, and to ensure that the project can be bid for construction.

5.3.7.1 Alternative Analysis and Concept Development

Alternative analysis involves the development, evaluation, and selection of a preferred concept for investigation through more detailed engineering and design. The combinations of design criteria and designer decisions create the conceptual design. The designer puts the pieces, or design elements, together, including both horizontal and vertical alignments, to create one or more project concepts or alternative solutions. The process is iterative and involves developing solutions that balance the benefits of project alternatives with the effects of the project. When more than one conceptual solution is developed for consideration, the concepts are compared to determine a preferred conceptual alternative to carry forward into more detailed evaluation and design.

Highway safety and design professionals now have the ability to use substantive safety and quantitative safety analysis to inform project development, design, and decision making, so that resources can be allocated toward the design with the greatest potential to benefit safety and not purely for the sake of meeting standards. Linking investment decisions to substantive safety outcomes rather than just to standards will allow an agency to make better and more cost-effective design decisions. Safety can now be evaluated quantitatively using the methods in Part B of the HSM, along with other design considerations, such as LOS, right-of-way, environmental impacts, and ultimately cost. That ability allows an agency to use safety as an evaluation factor for design alternatives and for balancing tradeoffs among evaluation criteria.

5.3.7.2 Design Exceptions

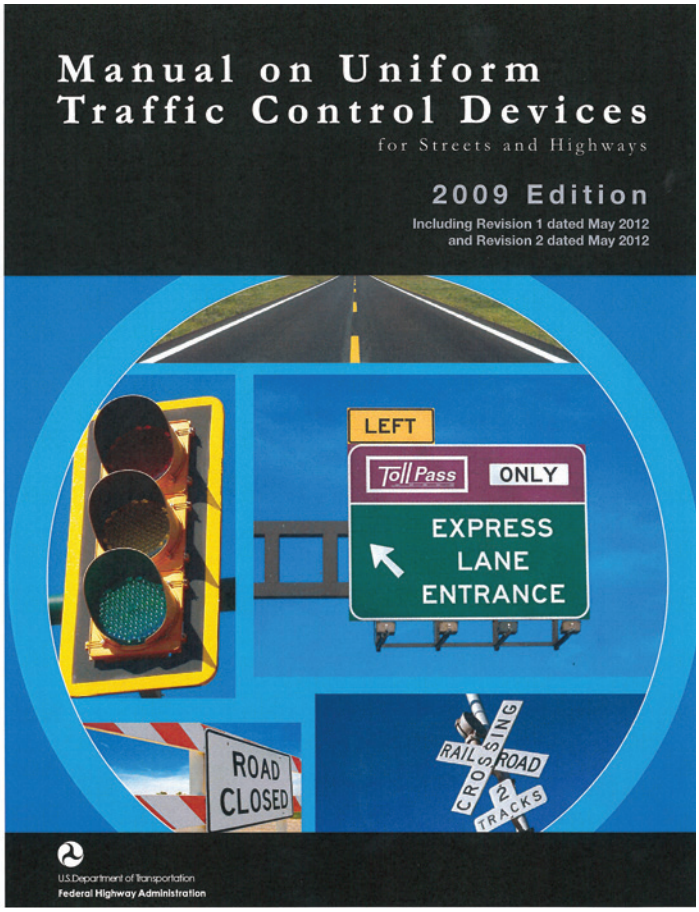
A design exception is a documented decision to select a value for a roadway feature that does not meet minimum values or ranges established for a particular project. FHWA requires a formal written design exception if those criteria are not met in an improvement to any route on the National Highway System. Design exceptions are used in situations where deviation from one or more of the controlling criteria add justifiable value or benefit to the project. If planners are to confirm that design exceptions are necessary, an alternative that provides the standard normally must be developed to demonstrate the adverse impacts or costs that result from meeting the particular criterion.

The safety effects of changes in design elements can generally be quantified using available crash prediction methods for some or all of the standard roadway segment and intersection types. The preceding section has provided information about the safety influence of design elements on safety performance, including those controlling criteria. Mitigative safety strategies can be identified to offset the safety effects of proposed alternatives and can be quantified using substantive safety methods. At a minimum, the designer should develop a mitigation strategy for sites that require design exceptions.

5.3.8 Application of Substantive Safety to Final Design

In the final design step, the work focuses more on providing the details and additional features necessary for preparing

Figure 5-11. Manual on Uniform Traffic Control Devices



plans, specifications, and a detailed cost estimate to be used in bidding and building the project. The work typically includes (a) completion of geometric and roadway details; (b) plans for control and maintenance of traffic during construction; (c) lighting, signing, and pavement marking plans; (d) utility relocation plans; (e) guardrail and barrier plans; and (f) plans for erosion control and storm sewerage.

During the final design step, revisions to the preliminary geometric plans are common. Typically, those revisions are associated with additional data obtained, constructability reviews, or final negotiations with affected stakeholders. Final design engineers need to keep their focus on the details to avoid issues during construction. However, they must not lose sight of the big picture and must ensure that any changes made do not adversely affect the operation of the facility. At the conclusion of this step, the project will have advanced to a stage at which the owner can procure construction services, most typically through a low-bid process involving qualified constructors.

In the final design, the details of such items as signs, pavement markings, and roadside safety hardware are developed. Those features must be developed with the attention to detail that will result in clear guidance for drivers. Some of the most severe crashes are the result of lane departures. The details for pavement markings, signs, and rumble strips can help keep drivers on the road. Pavement markings provide drivers with continuous delineation information as they travel along the road. Pavement markings communicate the alignment information, the number of lanes in each direction, and the location of the vehicle paths. To ensure that the proper information is communicated to drivers, pavement markings should conform to the *Manual on Uniform Traffic Control Devices* (MUTCD) (see figure 5-11).[17]

All traffic control devices should be located where they provide good visibility to optimize the advantage to drivers. Traffic signs are another important source of information for drivers. Consistently following the MUTCD ensures that drivers will recognize the sign messages. Proper placement of signs is necessary to provide the information where drivers will see it and where it is needed for the proper execution of the driving task. The MUTCD guidance is based on substantive safety in the application of the principles where the designer considers the following five requirements for any traffic control device:

- Fulfill a need.
- Command attention.
- Convey a clear, simple meaning.
- Command respect from road users.
- Give adequate time for proper response.

Length of need and proper placement of barriers that allow for required deflection are critical to the adequate performance of the barrier and the resulting safety of the roadway segment. Clear zones and lateral offsets of roadside appurtenances must be maintained as envisioned when the design was developed.

5.3.8.1 Maintenance of Traffic and Temporary Traffic Control

Motorist delay and safety are closely related: crashes cause congestion, and congestion causes crashes. Reduction of crashes in the work zone not only improves safety for the traveling public but also reduces risk to workers within and adjacent to the zone.

The design of temporary traffic controls, which include construction work zones and geometric alignments, is a careful balance of cost, effects, and service to motorists provided over the period of construction. The goal of all traffic maintenance and temporary traffic control plans is to reduce the exposure of motorists and workers to risk through and around construction areas. The three most effective approaches of accomplishing that goal are (a) to reduce the volume of traffic through the work zone itself by providing alternate routes, (b) to reduce the length of time that work zones are in place, and (c) to reduce the frequency of establishing work zones. A well-thought-out and carefully developed plan for the management of traffic will contribute

significantly to safe and efficient traffic flow and to the reduced potential for injury to construction workers.

Designers may have little influence over the overall frequency of work zones, but they can incorporate strategies that include methods such as nighttime or offpeak work to reduce the work zone's effect on traffic or innovative incentive-based contracting to shorten work zone duration. However, such strategies may not be feasible for every project, nor do they eliminate all risks. Therefore, the designer must consider the context of the temporary traffic control design and must integrate a range of strategies into the design plans for properly managing the work zone during construction. Accommodation of pedestrians and cyclists must also be considered in work zones. The most effective plans include strategies and methods both to reduce the risk of crashes and to minimize severity when crashes do occur. A well-developed plan should also have some built-in flexibility to accommodate unforeseen changes in construction schedule, delays, and traffic operations.

Transportation Management Plans. In September 2004, the FHWA published updates to the work zone regulations as 23 CFR 630, Subpart J. The updated rule is referred to as the Work Zone Safety and Mobility Rule, and it applies to all State and local governments that receive Federal-aid highway funding. The rule has been in effect since 2007. The purpose of the update was to address changing roadway conditions, including more traffic, more congestion, greater safety issues, and more work zones on highways. Those challenges require a systematic and structured approach to ensure consistent traffic management statewide. If one is to meet those challenges, the rule requires the development of transportation management plans for projects.

A transportation management plan is a set of coordinated transportation management strategies; it describes how they will be used to manage a project's work zone effects. Transportation management strategies for a work zone include (a) temporary traffic control measures and devices, (b) public information and outreach, and (c) operational strategies such as transportation operations and incident management strategies. The scope, content, and level of detail of a transportation management plan may vary according to the anticipated work zone effects of the project. A transportation management plan is required for all projects that are expected to result in a disruption in traffic flow for an extended time (i.e., not short term or temporary) or that are expected to increase traffic delay and congestion beyond that which is normally experienced at the project site.

The transportation management plan is a key part of a comprehensive project planning and development process and should be initiated early as part of the planning and programming phase. During planning and programming, effects are evaluated at a concept level. In preliminary engineering, effects are evaluated at the project level and need to be considered as part of the alternative evaluation process. In final design, the work zone traffic control plan comes together. At that point, the engineers and designers conduct a more detailed design-level assessment of the work zone effects of individual projects, including factors such as safety for all users (including pedestrians, transit, and bicyclists), speed, congestion, queuing, anticipated travel delay, phasing of construction, potential diversion of traffic, and adequate geometric design to facilitate movement of traffic. On the basis of those effects, agencies then develop transportation management plans, incorporating the appropriate temporary traffic control strategies and devices to address those effects.

Implementation of a well-designed transportation management plan minimizes work zone crashes and travel delay time and allows for reasonable access within and around the work zone, thus improving quality and allowing for timely completion of work. For projects with lesser effects, a traffic control plan is sufficient to fulfill the requirements of a transportation management plan.

Manual on Uniform Traffic Control Devices. The MUTCD describes the policies and guidelines for establishing proper work zone traffic control and management. It provides the recommended guidance for all temporary traffic controls—advance warning for drivers approaching a work zone as well as the use of traffic control devices for guiding all users safely through the work zone. All traffic control devices used in work zones and along alternate routes should conform to the MUTCD. Conformance provides the consistency needed to keep drivers well informed of the appropriate action to take.

The MUTCD provides guidance that considers the information needs of motorists and all other users. Part 6 provides guidance about the traffic control devices for each of the four areas within the work zone: (a) the advance warning area, (b) the transition area, (c) the activity area, and (d) the termination area.

The following key strategies and devices are recommended for use in work zones to help maintain efficient traffic flow and to minimize disruptions to users that can lead to crashes:

- **Pavement Markings**—Pavement markings provide guidance to drivers in the form of a clear path through the work zone and are important for safety on all roadways. They are especially important for delineating where traffic lanes vary from permanent lanes, where they cross, or where they do not line up with joints in the pavement. It is important to remove or obliterate pavement markings that conflict with or that are inapplicable for the current stage or phase of traffic control.

- **Channelizing Devices**—Raised reflective pavement markers, reflectors on temporary barricades, or delineators can provide guidance and warning to roadway users. Channelizing devices provide increased information on the proper route through a work zone and can reduce lane-departure crashes.
- **Barriers and End Treatments**—Barriers provide motorists with guidance and protection by separating the traffic from the work area. A barrier will prevent vehicles from entering the work area where a crash could occur with workers or construction equipment. Paddles or glare screens can be placed on barriers to reduce the distraction to drivers from the work taking place.
- **Diversions and Detours**—If one is to expedite construction work, it may be more efficient to close the road and allow the contractor to work on the entire site. That approach requires a detour route for the traveling public. Even when the road is not closed, the capacity on a roadway under construction will usually be less when a work zone is implemented. Providing an alternate route to divert at least some traffic will help reduce the volume of traffic and delay through the work zone. For example, reducing the level of congestion can help reduce rear-end crashes in the work zone.
- **Portable Changeable Message Signs and Other ITS Applications**—Changeable message signage can help provide motorists and other users with up-to-date information and guidance. For example, informing drivers in advance of an incident or warning them of any condition ahead that requires action on their part helps reduce secondary crashes and gives drivers an opportunity to select an alternative route (see figure 5-12).
- **Emergency Response Provisions**—When shoulders cannot be provided through a long work zone, pulloff areas should be provided. Access-controlled routes may need a temporary emergency access to allow emergency responders to get to crashes or incidents. Pulloffs can also provide locations for enforcement efforts.

Permanent vs. Temporary Pavement and Infrastructure. The approach to designing temporary roadway facilities through work zones is similar to the process of designing the permanent facilities. However, there are some key differences. Typically, much more emphasis is placed on the costs and effects of the construction of temporary facilities. Expenditure of highway funds and the effects on the surrounding properties are more difficult to justify when the life of the temporary facilities is just for the duration of the construction. The construction and removal of temporary roadway facilities are warranted and can be better justified when it is necessary to provide all users with mobility and safety and the needed levels of access. The cost of temporary infrastructure must be weighed against the need for service, duration of effect, and safety considerations on the route.

Figure 5-12. Portable Changeable Message Sign

The LOS that a roadway provides is influenced by its capacity, horizontal and vertical alignment, and cross-sectional features such as access. For example, where temporary pavement ties to permanent pavement, the cross slope provided is often not what it would be for permanent facilities, especially when the alignment has horizontal curves and would be superelevated. Lane consistency is very important. Wherever feasible, the existing and newly constructed pavement should have a similar number of lanes for traffic. That may be done by using paved shoulders and by narrowing lanes from 12 feet to as few as 10 feet. Changes in traffic operation, such as reducing the speed limit, and adequate warning signs can help mitigate such modifications.

Typically, there are more constraints on the design of the temporary roadways associated with construction work zones than on those for permanent roads, simply because of the reduced roadway cross section and the potential changes in road elevation that may occur. Temporary roads must connect to existing roads and must provide for safe travel around the construction operations. Temporary facilities are usually designed to a lower threshold or standard than is the permanent roadway. It is common to use a design speed that is 10 miles per hour below the existing design speed on the facility.

Warning signs with advisory speeds and reduced speed limits are provided to inform drivers that they should reduce their speed through the area. However, the speed and design element differential creates inconsistencies between adjacent segments (permanent to temporary), as noted earlier in this document, and should not be considered a preferred condition. That is not to say that maintaining the existing speed and providing for higher design standards in work zones are the solution. It is important, however, for practitioners to understand those design and safety relationships and to consider whether other strategies can be integrated into maintenance of traffic and temporary traffic

control plans to mitigate the effects of speed differentials and differing roadway conditions.

Many of the same issues and complications apply to other users. For example, a wide range of pedestrians might be affected by work zones. If applicable, those users need a clearly delineated and usable travel path that replicates as nearly as possible the desirable characteristics of existing sidewalks or footpaths.

5.3.8.2 Value Engineering

Value engineering (VE) is defined in 23 CFR 627.3 as

> *… the systematic application of recognized techniques by a multidisciplined team to identify the function of a product or service, establish a worth for that function, generate alternatives through the use of creative thinking, and provide the needed functions to accomplish the original purpose of the project, reliably, and at the lowest life-cycle cost without sacrificing safety, necessary quality, and environmental attributes of the project.*[18]

As specified in 23 U.S.C. 106(e), VE analyses are required on all projects that use Federal-aid highway funding with an estimated total cost of $25 million or more and that are part of the National Highway System, as well as on all bridge projects with an estimated cost of $20 million or more that are on or off the National Highway System and that use Federal-aid highway funding.[19] The VE analysis is performed before completing the final design. All approved recommendations must be included in the project's plans, specifications, and estimates. In addition to those projects where the FHWA requires a VE study, the VE process provides value to other projects where the owning agency believes that it may be beneficial to have a team review the design for opportunities to reduce cost or increase value.

To save money, VE study teams sometimes recommend the following: reducing the number of lanes, narrowing lanes or shoulders, reducing structure area, steepening side slopes, shortening tapers, or reducing auxiliary lane lengths. Safety expertise should be included on the VE team so that "value" can be properly assessed. The safety expert should fully brief the VE team on the operational and safety effects of the design features. Quantitative safety can be applied in the VE process to quantify the safety effects of VE opportunities identified by the VE study team. The safety effects of any accepted VE recommendations that revise any features in the final plan should be assessed.

5.3.8.3 Final Design and Safety Review

During the design process, the designer considers options across multiple geometric elements such as lane and shoulder width, curve radii, and grade. The design process involves choices and tradeoffs. Design manuals and standards are certainly important, but balancing (a) the quantitative, science-based safety effects of a design parameter against traffic operations; (b) the accommodations of all users; and (c) the cost allows the designer to make overall cost-effective choices regarding system performance.

Final design is the stage where all the project planning, alternative analysis, and project considerations come to an end; where plans are finalized; and where adjustments are made (a) to fit the design within the limits of the right-of-way, (b) to address utility conflicts, and (c) to finalize the design details. It is natural for the final process to involve and affect some of the early planning and preliminary design decisions. As standard practice, the designer or agency should build into final design reviews a review comparing the project analysis and design decisions regarding safety against the final plans. Where changes have been made that affect design elements to the extent that safety may be affected, the designer or agency can use quantitative analysis to measure that effect. It is never too late, whether in final design or even in construction (chapter 6), to implement additional treatments to adjust changes in design that may influence safety performance.

5.4 TOOLS AND RESOURCES FOR INTEGRATING SAFETY INTO ENGINEERING AND DESIGN

Safety-conscious design principles and alternative analysis using substantive safety techniques can be evaluated in the design process using two general approaches: (a) highway safety predictive methods and (b) crash modification factors. Applying substantive safety in engineering and design relies heavily on using those methods. Agencies have at their disposal the various analytical tools for applying those methods. Tables 5-2, A-1, and A-2 list the most commonly applied tools for quantitative safety analysis in engineering and design, as noted throughout this chapter, and it provides a snapshot of the current best practices for applying substantive safety. The list is not all-inclusive. New tools continue to be developed as the state of practice in substantive safety evolves.

5.5 REFERENCES

1. American Association of State Highway and Transportation Officials, *Highway Safety Manual*, 1st ed. (Washington, DC: AASHTO, 2010).
2. Federal Highway Administration, Crash Modification Factors Clearinghouse website, http://www.cmfclearinghouse.org/.
3. Federal Highway Administration, *Integrating Road Safety into NEPA Analysis: A Practitioner's Primer* (Washington, DC: FHWA, 2011).
4. Ibid.
5. Federal Highway Administration, Road Safety Audits (RSA) website, http://safety.fhwa.dot.gov/rsa/.

Table 5-2. Sources for Integrating Safety into the Three Engineering and Design Steps

Tools and Resources	Project Scoping/ Planning	Preliminary Engineering	Final Design
Crash Modification Factors Clearinghouse	●	●	
Enhanced Interchange Safety Analysis Tool (ISATe)		●	●
Highway Safety Manual Part B Roadway Safety Management Process	●	●	
Highway Safety Manual Part C Predictive Models		●	●
Highway Safety Manual Part D CMFs	●	●	
Interactive Highway Safety Design Model (IHSDM)		●	●
NHCRP 17–38 spreadsheets—HSM Predictive Methods Tools		●	●
Road Safety Audit (RSA); Road Safety Audit Review (RSAR)	●	●	●
Roadside Safety Analysis Program (RSRAP)	●	●	
Safety Analyst—HSM Part B Analysis Tool	●		
Integrating Road Safety into NEPA Analysis: A Practitioner's Primer	●	●	
Mitigation Strategies for Design Exceptions		●	●
NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan	●	●	
NCHRP Report 600: Human Factors Guidelines for Road Systems	●	●	●
Roadside Design Guide	●	●	●
Toolbox of Countermeasures for Rural Two-Lane Curves	●	●	

6. Ibid.
7. National Cooperative Highway Research Program, *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan*, vols. 1–23 (Washington, DC: Transportation Research Board, 2003–2009).
8. AASHTO, *Highway Safety Manual*.
9. Federal Highway Administration, Proven Safety Countermeasures website, http://safety.fhwa.dot.gov/provencountermeasure/.
10. Institute of Transportation Engineers, *Designing Walkable Urban Thoroughfares: A Context Sensitive Approach* (Washington, DC: ITE, 2010).
11. Ibid, 108.
12. Transportation Research Board, *Highway Capacity Manual*, 5th ed. (Washington, DC: TRB, 2010).
13. American Association of State Highway and Transportation Officials, *A Policy on Geometric Design of Highways and Streets,* 6th ed. (Washington, DC: AASHTO, 2011) (the Green Book).
14. American Association of State Highway and Transportation Officials, *A Policy on Design Standards: Interstate System*, 5th ed. (Washington, DC: AASHTO, 2005).
15. American Association of State Highway and Transportation Officials, *Roadside Design Guide,* 4th ed. (Washington DC: AASHTO, 2011).
16. National Cooperative Highway Research Program, *NCHRP Report 600: Human Factors Guidelines for Road Systems*, 2nd ed. (Washington, DC: NCHRP, 2012).
17. Federal Highway Administration, *Manual on Uniform Traffic Control Devices* (Washington, DC: FHWA, 2009).
18. Federal Highway Administration, *Integrating Road Safety into NEPA Analysis: A Practitioner's Primer* (Washington, DC: FHWA, 2011); Federal Highway Administration, Road Safety Audits (RSA) website, http://safety.fhwa.dot.gov/rsa/.
19. "Value Engineering Analysis," 23 U.S.C. 106(e); Federal Highway Administration, Value Engineering webpage, http://www.fhwa.dot.gov/ve/vepolicy.cfm/.

5.6 ADDITIONAL READING

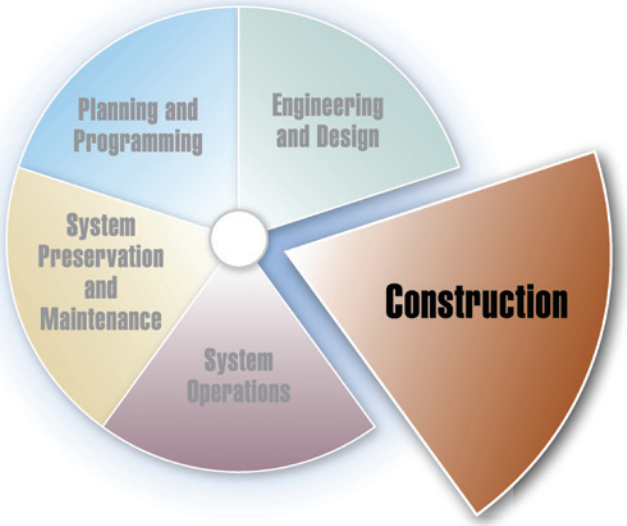
1. Transportation Research Board, *Access Management Manual* (Washington, DC: TRB, 2003).
2. Federal Highway Administration, *Toolbox of Countermeasures and Their Potential Effectiveness for Pedestrian Crashes*: FHWA-SA-014 (Washington, DC: FHWA, 2013).

WORK ZONE SAFETY

6

Photo courtesy of Thinkstock.

Figure 6-1. Construction in the Project Development Process



Source: CH2M HILL.

6.1 INTRODUCTION

The construction phase is the beginning of actual implementation of the improvement project (see figure 6-1). Many different challenges exist to the successful mitigation of safety issues in roadway work zones. The presence of workers and construction equipment operating near travel lanes or pedestrian and bicycle paths creates an inherently high-risk situation. The number of travel lanes open to traffic changes often, sometimes from day to day. With the work area occupying a part of the road or roadside, the area available to travelers usually does not have the benefit of all the safety features on the permanent roadway facility, such as full shoulders, unobstructed clear zone, usable sidewalks, and so forth.

The work being done adjacent to the open roadway lanes creates a distraction for drivers and places an additional demand on drivers' attention. The facility should continue to serve all users accommodated by the existing facility. In addition to the travel lanes for vehicles, the facilities along the side of the

Table 6-1. Typical Traffic Management Approaches

Work Zone	Short-Term Maintenance	Resurfacing	Patching/ Repair	3R Project	Reconstruction in Place	Reconstruction New Alignment
Close one lane while work is conducted	•	•	•			
Use flaggers with one-way operation	•	•	•			
Long-term lane closure for multilane highway		•	•	•	•	
Long-term multilane closure				•	•	
Shoulder or lane closure for adjacent work				•	•	•
Temporary work access					•	•
Construct temporary road/lanes					•	
Close road sign USE ALT ROUTE					•	
Close road with signed detour route					•	

roadway that accommodate other users, such as pedestrians, bicycles, and transit riders, are greatly affected by construction activities.

The major construction-related safety issues for motorists involve reconstruction projects, whereby the road remains open to traffic. Safety practices during construction focus on keeping the facility as safe as possible for all users of the roadway and for the workers on the site. Agencies apply many performance measures and analysis methods throughout project development to aid in developing the work zone strategies to be included in the design. Substantive safety knowledge can inform not only the project design but also the work zone safety and design strategies built into the maintenance of traffic criteria applied during construction.

This chapter has the following objectives:

- Provide an overview of key aspects of roadway construction conditions that have bearing on what constitutes safety performance; on how those aspects differ from standard traffic operations and design; and on how substantive safety can be used to quantify, identify, and evaluate safety management practices during construction.
- Show how an agency can incorporate substantive and nominal safety considerations into the construction phase of project development.
- Describe the steps to evaluate safety in the construction phase of project development.

6.2 OVERVIEW OF CONSTRUCTION

The construction phase of the project development process (PDP) begins after the final design has been completed. In the actual implementation of the improvement project, the design becomes reality. Temporary roadway work zones are a means to facilitate construction as a project proceeds. Chapter 5 discusses the design aspects of developing a plan to maintain safety within a work zone while minimizing the negative effects on travelers. This chapter focuses on the implementation of those plans.

Agencies consider various benefit–cost factors when making decisions on construction activities, particularly concerning how a project will be built and what construction methods will be used.

The type of work, the level of activity, and the duration of the work are factors that must be considered in the decision on how to accommodate the traveling public during the construction of the project. Typical traffic management approaches for the various types of projects are shown in table 6-1. There are tradeoffs between (a) closing the road and detouring traffic to an alternate route (see figure 6-2) and (b) constructing an improvement project while allowing traffic on a portion of the road (see figure 6-3).

Constructing the road in smaller sections and having more traffic control work for various stages will increase the duration and cost of construction. Closing the road to traffic gives the contractor access to the entire route, making it possible to build larger portions, which, in turn, allows more efficient construction operations and staging. However, closing the road and providing a detour will cause more delay for motorists than would keeping some lanes open for travel through the work zone.

Conversely, allowing traffic while construction is underway requires a balance between the contractor work area and the primary route's travel way. When traffic is allowed, duration of construction may be longer, and different construction strategies with differing implications for cost and effects may be required. The decision on whether to close a road for construction must also consider the effect on other users. Alternative routes that add a small amount of additional travel time for motorists may involve significant additional time, may be difficult to use, or may be less safe for pedestrians or bicyclists.

One objective in selecting a construction method, in staging, and in enabling continuity of traffic is to maintain traffic flow and safety for motorists, construction workers, and those in sites adjacent

Figure 6-2. Closing the Road Allows Contractor Complete Access to the Site

Figure 6-3. Construction under Traffic

to work zones. The adjacent land use has a big influence on the accommodation of traffic through the construction zone. Access to adjacent properties must be maintained. Keeping that access requires significant coordination with the adjacent property owners.

6.3 SUBSTANTIVE SAFETY CONSIDERATIONS

6.3.1 Work Zone and Construction Safety

Maintaining road user and worker safety and accessibility in work zones is an integral and high-priority element of every project during construction. Work zones pose challenges in safety management as agencies balance the needs of their workers within the construction site and adjacent areas with those of the traveling public. Work zones can result in congestion and delay, can lead to crashes and related losses, can cause adverse effects on communities and businesses, and can increase driver frustration. But the need to improve or construct new street and highway facilities, preserve existing roadways, and perform maintenance makes temporary work zones unavoidable.[1]

Some limited research and information exists about measuring the quantitative effects of safety in work zones. Nevertheless, the industry still relies heavily on judgment and standard practice in mitigating work zone safety issues. Simply put, the research and development about quantifying safety in construction is not as extensive as for other phases of the PDP. Most of available safety research focuses on the design of roadway facilities, which limits the application of those analytical methods to construction conditions. Work zone conditions vary in design features, to the extent that current research models (which focus on evaluation of completed design and the built environment) are not an ideal fit to work zone conditions. Similar to design applications, expected safety performance for work zone conditions would be determined by inherent differences in work zone conditions.

Although the tendency has been to use nominal safety as the benchmark against which work zone criteria are measured, the knowledge base and industry trends suggest that the frequency of crashes within a work zone is, in fact, context sensitive. In some cases, methods exist for estimating the safety influence of some conditions on work zone safety. Specifically, work zone duration and length, as well as average daily traffic, influence the frequency of crashes within a work zone.[2] Crash modification factors (CMFs) found both in the *Highway Safety Manual* (HSM)[3] and on the CMF Clearinghouse website[4] can be applied to estimate the relative effect of differences in those parameters as well as other work zone conditions.

Still other research indicates that some effects on the safety performance and expected crash frequency in work zones can be attributable to changes in design elements, such as shoulder width. However, the knowledge base and available research for defining those effects on work zones are still limited compared with those for standard design conditions.

6.3.2 Integration of Substantive Safety into Construction

The principles of substantive safety and the known influence of changes in certain design elements apply to work zones and to traditional design conditions—even if they cannot yet be quantified with models that are specific to work zone data analysis. Best practices in work zone safety management[5] encourage work zone traffic management policies that are customer-driven and comprehensive and that focus on reducing the exposure of both travelers and construction workers.

Policies and practices include (a) establishing high-quality design, construction, and maintenance operations; (b) minimizing disruption to drivers; and (c) maintaining a safe,

efficient roadway environment for drivers and highway workers. Where substantive safety is concerned, knowledge of the substantive effects of changes in design elements can be used in designing the work zone, responding to and treating observed work zone safety issues on the project level, and proactively mitigating common work zone safety issues at the program level.

6.3.2.1 Considerations of Driver Characteristics

Two categories of drivers present challenges to the design of construction work zones:

- **Unfamiliar or Occasional Drivers—**Drivers who do not know what to expect may take longer to react to the conditions they encounter in a work zone. Changes in lane configuration since the last time an occasional driver traveled through an area may lead to delayed or inappropriate responses.
- **Commuters—**Commuters who drive the same route daily develop habits and often do not pay as much attention to surroundings as less familiar drivers might. Commuters have a tendency to miss changes in signing or traffic control devices. Some agencies require that flags or flashers be attached to signs to attract the notice of regular users. The use of oversize signs may also help gain the attention of regular commuters.

The National Cooperative Highway Research Program's *Report 600: Human Factors Guidelines*[6] provides a framework for characterizing work zone crashes, offers observations about the effect of various work zone crash characteristics, and provides guidance on design elements of work zones intended to mitigate safety issues in work zone design.

Research findings about crashes in work zones as they relate to human behavior identify the need for additional and better guidance in work zones. Rear-end crashes were found to be the most common crash type within work zones. Design elements that focus on reducing speed variance and providing speed control are very important for increasing safety in work zones.

6.3.2.2 Temporary Traffic Control and Work Zone Management

The purpose of a temporary traffic control and work zone management plan is to anticipate and describe traffic control measures that will be necessary during project construction and to outline coordination needs with owner agencies, adjacent property owners, and the public. The development of temporary traffic control begins very early in project development. It determines the nature and volume of current and predicted traffic and can vary widely in scope and complexity, depending on the type and volume of traffic and the nature of the construction project. The temporary traffic control plan's features become the contractor's obligations and thus are included in the plans and specifications.

Temporary traffic control features are often integral to the project design. When the construction crew encounters conditions that have been changed or are inconsistent with what is indicated in the plans, design changes may be required during construction. Those changes can have a significant effect on safety. The construction staff needs to be aware of the safety implications of changes to design and the need to coordinate with the people who decided the design details. Safety analyses should be conducted to determine whether safety features incorporated into the original design are being maintained.

Although data and analysis methods for quantifying crash frequency and severity in work zones are limited, the transportation professional can apply the same principles of safety used in the design of the permanent facility to the roadway facility during construction. Integration of substantive safety into work zone safety and the construction phase of the PDP need not depend solely on the ability to quantify safety performance through prediction of crash frequency or severities. When data and analysis are lacking, the substantive safety knowledge base will provide valuable guidance on selecting and applying safety countermeasures in work zone design to proactively mitigate known work zone safety issues. Where data are limited, even a modest analysis of crash trends in work zone conditions can help identify and diagnose work zone safety issues as they develop. Similarly, trend analysis on a program level can help an agency assess how well its work zones are operating, can aid in developing and managing work zone safety programs, and can guide improvements in work zone safety performance and management.

6.3.2.3 Manual on Uniform Traffic Control Devices

The *Manual on Uniform Traffic Control Devices* (MUTCD)[7] is the guide to setting up proper work zone traffic control. It provides the recommended practice for advance warning for drivers approaching the work zone as well as the use of traffic control devices for guiding traffic safely through the work zone. The traffic control devices used in work zones and along the entire route should conform to the MUTCD. Doing so provides the consistency needed to keep drivers well informed of the appropriate action for performing the driving task properly.

The MUTCD considers the information needs of motorists. Part 6 provides guidance about the traffic control devices for the four areas within the work zone: the advance warning area, the transition area, the activity area, and the termination area.

6.3.2.4 Accommodation of Pedestrians and Bicycles

Construction activities sometimes encroach on sidewalks or crosswalks that provide a pedestrian path through the work zone. Temporary facilities must be provided so that pedestrians are not guided through the work area or into traffic. Most urban projects are constructed in phases. The construction zone changes frequently, which adds to the challenge of maintaining a safe path for pedestrians.

The Americans with Disabilities Act requires that pedestrians with disabilities be accommodated during construction and on the completed facility. The pedestrian path should be comparable to the accommodation of the existing sidewalks. If pedestrians are routed closer to traffic than with the permanent facility, a traffic barrier may be required. Barriers or fences should be provided to keep pedestrians out of the work area.

In some cases, a suitable, continuous pedestrian path may not be available, even if sidewalks are on both sides of the road. It may be necessary to install a temporary crosswalk at each end of the project and to require pedestrians to cross the road and use the sidewalk on the other side to detour around the work zone. Bus stops or pedestrian access to adjacent properties may have to be relocated temporarily. Where done, signs should be installed to inform pedestrians of sidewalk closures or any amenities that have been temporarily relocated.

Where bicycle facilities exist, they should be maintained through or detoured around the construction zone. If enough paved lane width cannot be maintained for vehicles to pass bicycles safely, setting up a detour route for the bicyclists may be advisable.

6.3.3 Application of Substantive Safety to Construction

In the absence of a compendium of knowledge and research about the quantitative effects on safety of changes in work zone design, the transportation professional can rely on the application of best practices in construction that consider the substantive effects of changes in design. The following sections present best practices for applying substantive safety to the construction phase of project development.

Although this chapter focuses on the safety of the travelers using the facility, the practices described can help protect workers on the site as well.

6.3.3.1 Construction Road Safety Audits and Prompt List

Three types of road safety audits (RSAs)[8] are conducted during the construction phase of the PDP:

- **Work Zone RSA for the Traffic Control Plan—**The basic principles of an RSA are used to conduct a Work Zone Road Safety Audit. The Work Zone RSA focuses on the work zone design, operations, and safety. Work Zone RSAs are conducted by a multidisciplined team. However, conducting a Work Zone RSA does not eliminate the need for regular inspections of the work zone's traffic control to ensure that the traffic control devices remain in working order. The book titled *FHWA Road Safety Audit Guidelines* contains the prompt list for a Work Zone RSA.[9]
- **RSA of Changes in Design during Construction—**An RSA of changes in design during construction is basically the same as the design stage RSA. This type of RSA is normally conducted only when a substantial change in the design is made during the construction phase of the PDP.
- **Preopening RSA—**The preopening RSA is the last opportunity for the facility's owning agency to make safety improvements before opening the facility to traffic. It includes a detailed inspection of the newly constructed facility and of where it ties into the road network. An inspection should be conducted both at night and during daylight hours. Because a preopening RSA takes place following construction, significant physical changes are not usually feasible.

  RSA suggestions may focus on illumination, pavement markings, signing and delineations, roadside barriers, and detailed connections of pedestrian or bicyclist accommodations. It may also point out incorrectly located or poorly installed features, such as poles, barriers, other safety devices, and temporary obstructions overlooked during site cleanup. Sometimes, minor changes can reduce safety risk at minimal cost. FHWA *Road Safety Audit Guidelines* contains the prompt list for a preopening RSA.

6.3.3.2 Performance Monitoring and Evaluation

Consideration of substantive safety in the development of work zone performance monitoring and evaluation will help agencies improve how they make decisions regarding work zones. Similar to the application of quantitative safety analysis to the planning and programming and the design and engineering phases of the PDP, a data-driven analytical process for monitoring and evaluating the safety performance of work zones is critical for the successful application of substantive safety concepts during construction. FHWA's *Primer on Work Zone Safety and Mobility Performance Measurement*[10] describes the need for agencies to establish performance measures for monitoring the effects of work zones on travelers, residents, businesses, and workers. Three basic types of measures are identified: exposure, safety, and mobility. Integral to all those measures are the collection, analysis, and use of work zone data.

The process for developing such a program is scalable; agencies can develop work zone safety performance measures that can be applied at the project level, the program level, or both. Agencies may choose to consider a selection of measures on the basis of available resources and other factors in determining the most appropriate sources or methodologies to use. Alternatively, agencies may choose first to select work zone performance measures and then to define the data sources, the collection techniques, and the calculation methodologies necessary to perform the calculations. Regardless of the approach, the key to successful performance monitoring is selecting measures on the basis of needs and characteristics that also consider stakeholders' priorities.

6.3.3.3 Transportation and Traffic Management Plans

The regulation referred to as the Work Zone Safety and Mobility Rule[11] applies to all State and local governments that receive Federal-aid highway funding. FHWA requires that a Traffic Management Plan (TMP) be prepared for any project with the potential to affect safety and mobility adversely. To aid agencies in their understanding of the rule, FHWA has published a guidance document.[12]

The TMP should safely guide traffic through the construction project area and should consider the safety and mobility effects of work zones across project development. An effective TMP guides implementation of strategies that help manage those effects during project delivery. FHWA encourages agencies to consider temporary traffic controls early in the design, so that additional strategies can be assessed while revising the design is still a possibility. When selecting the preferred alternative, some agencies compare the benefits with the costs of the traffic control requirements of the various alternatives during construction. Traffic analysis completed early in the process can help determine whether the service provided on a restricted section will be acceptable or whether mitigation improvements are necessary to accommodate the traffic in another way, such as improvement to an adjacent route to divert some of the traffic.

6.3.3.4 Work Zone (Law) Enforcement

Law enforcement officers enforce traffic laws and encourage safe conditions in work zones. Those best practices employ full-time uniformed police officers who are trained and qualified in work zone traffic laws and who are readily available for construction operations.[13] Law enforcement should be used where speed reduction and awareness of work zones are not accomplished adequately with signing and work zone channeling devices. The following work zone enforcement activities have documented substantive safety benefits:

- **Automated Enforcement—**Automated speed enforcement in confined and high-speed work zones has proved effective in some locations. However, the laws in some States do not allow automated enforcement.
- **Enforcement Areas—**The most common use of law enforcement officers during construction is for visible enforcement of speed limits through the work zone and for more orderly merging where the number of lanes through the work zone is reduced. Planned enforcement areas may be needed in the traffic control plan. If not planned for, it may be difficult for officers to pull over vehicles for violations.
- **Penalty Enhancement—**All States increase the penalty of certain traffic offenses, usually speeding, that occur in work zones. Some States will also increase the penalty for traffic violations related to incident clearance within a work zone. For example, several Wisconsin statutes contain the following typical language:

  If an operator of a vehicle violates various sections related to (specific offenses) where persons engaged in work in a highway maintenance or construction area or in a utility work area are at risk from traffic, any applicable minimum and maximum forfeiture specified in (various subsections) for the violation shall be doubled.[14]

6.3.3.5 Worker Safety and Visibility Training

Section 5204(e) of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) provides authority for States to use funds from five primary core programs to support training, education, and workforce development regarding worker safety in construction work zones. That funding can be used for roadway safety training courses, such as safety training for traffic control technicians and traffic control supervisors.[15] Most State departments of transportation have taken advantage of those funds to ensure that their workers receive roadway safety training.

6.3.3.6 Emergency Assistance and Incident Management

To facilitate coordination between emergency responders and the construction team on limited-access facilities, an agency may use emergency vehicle access points during construction. Keeping equipment located where it can be readily implemented to respond to incidents will reduce response time on large freeway projects. Patrol vehicles equipped to help repair disabled vehicles or to move them from the travel lanes will quickly help reduce congestion and additional crashes caused by the queuing of vehicles following an incident.

6.3.3.7 Intelligent Transportation Systems Tools

Intelligent transportation systems (ITS) apply various technologies to monitor, evaluate, and manage transportation systems to enhance efficiency and safety. Several strategies can be applied during construction to benefit the safety performance of a work zone:

- **Real-Time Delay and Alternate Route Information—**Real-time delay and alternative route information can be provided on an agency's website. Dynamic message signs can be implemented to inform motorists of the anticipated delay on the route under construction and of alternate routes. Providing real-time traffic and lane closure information can enable drivers to choose alternate routes and transportation modes, thereby reducing travel times and delays caused by incidents. Congestion is reduced, and travel speeds increase and become more consistent. The reduction in congestion and more consistent travel speeds lead to fewer rear-end crashes.
- **Dynamic No-Passing Zones—**The Indiana Department of Transportation's dynamic no-passing zone system uses a series

of signs that display the message "Do Not Pass When Flashing." The signs are placed upstream of a construction zone, and each has a set of flashing amber beacons that can be activated automatically. When the congestion at a construction site begins to increase, signs farther upstream are activated, expanding the length of the no-passing zone and directing vehicles to change lanes before the point of congestion. The system was developed to help address the issue of drivers staying in closed lanes until the last moment and then making abrupt lane changes.[16]

- **Motorist Awareness System—**During construction, if lanes are closed and workers are present, the speed limit is reduced. Motorists are warned of the speed limit change in the work zone by flashing regulatory signs, by radar speed-display units, and by the increased presence of law enforcement.

6.3.3.8 Work Zone Traffic Control

Transportation management strategies for work zones should include temporary traffic control measures and devices to provide adequate guidance and driver information. Managing traffic requires continuous monitoring and updating of the traffic control as traffic flow and construction scheduling change. The following are some key notable traffic control applications with a significant effect on safety performance in work zones:

- **Consistency in Traffic Control and Pavement Markings—**Traffic control changes from one stage of construction to the next, so it is important to convey the necessary information to drivers. Replacing or moving signs is easily overlooked. Signs that are inappropriate for the current stage of construction must be covered or taken down to avoid motorist confusion. Pavement markings provide guidance to drivers through the work zone. However, temporary pavement markings are often difficult to see in wet or bright sunlight conditions. Proper "obliteration" of permanent, conflicting markings is also an important issue. Incomplete removal of old pavement marking can lead motorists to drive out of the intended lane through the work zone. Raised reflective markers, delineators, or tubular markers can supplement the pavement-marking applications where it is difficult for drivers to see the markings. Those devices clarify the path that drivers need to follow through the work zone, thus reducing the incidence of lane-departure crashes.
- **Portable Changeable Message Signs—**Changeable message signs are well suited to the altering nature of the road construction work. They should be placed in advance of closures or changes that affect the route or path through the work zone. Messages may be operator controlled or triggered by ITS sensor data that are portable within the work zone. Additional information that avoids expectancy violations by drivers helps with the performance of the driving task and reduces crashes of all types.
- **Portable or Temporary Rumble Strips—**Because work zones are temporary in nature, there is a need for rumble strips that can be installed and removed quickly and efficiently while providing the same auditory and tactile warnings as permanent rumble strips. The circumstances and restrictions of work zones can vary greatly, and transverse rumble strips can alert drivers to the changing conditions and to the information being provided by temporary traffic control devices. The rumble strips are a safety countermeasure that provides both audible warning and physical vibration to alert motorists as the vehicle's tires traverse them. Because no specific message is associated with rumble strips, they can be used to alert motorists to a variety of conditions.

  The MUTCD indicates that transverse rumble strips, which extend across the travel lanes, are intended to notify road users of upcoming hazards or changes in roadway features, such as (a) unexpected changes in alignment and (b) conditions requiring a reduction in speed or a stop.[17] Rumble strips can be used for lane closures, speed reductions, changes in alignment, new merge patterns, visual obstructions, nighttime work zones, and any other condition that motorists would not expect to encounter. The American Traffic Safety Services Association, with support from FHWA, has developed guidance on the use of temporary rumble strips in work zones.[18]
- **Safety Edge—**The Safety Edge℠ is a proven safety countermeasure that can be implemented on roadways. The edge of the roadway is shaped at an angle of roughly 30 degrees from the pavement cross slope during the paving process. The Safety Edge mitigates pavement edge–related crashes and eliminates "tire scrubbing" that can occur when the driver attempts to recover after the tire leaves the pavement surface. Without the Safety Edge, a vertical or near-vertical pavement edge can become exposed. If the driver overcompensates by steering too hard, the vehicle can fishtail, swerve into another lane, or go off the road entirely.[19]
- **Temporary Traffic Barriers—**Temporary barriers guide motorists and protect them from dropoffs, equipment, or fixed objects. Temporary barriers should be used wherever conditions would be hazardous to users and the duration is long enough to make them cost-effective. Temporary barriers protect workers in the work zone from errant vehicles and protect the occupants of errant vehicles from fixed objects, dropoffs, and other hazards within the work area.
  - Most agencies use temporary concrete barriers. Heavy equipment is needed to place sections of barrier. The barrier's performance depends on the segment length and mass. The segments are made to be tied together so they may act as a system. Concrete barriers require crash cushions or need to be extended beyond the clear zone. Various shapes and styles of barrier are available.

- Water-filled barriers are made of polyethylene plastic and are filled with water to provide weight and stability. This type of barrier can be placed without the heavy equipment required to place concrete barriers, while providing improved driver guidance in construction zones. For water-filled units to perform as a barrier, they must have an internal or external steel framework. For temporary use, the ends of the water-filled barriers can also serve as an end treatment.[20]

6.3.3.9 Other Work Zone Safety Strategies and Best Practices

The tools and resources discussed earlier in this report can be used to make safety decisions. Chapters 4 and 5 should be consulted when planning, designing, and implementing safety strategies for construction. Several concepts mentioned in those chapters have benefits specific to construction that are worthy of noting, and there are several additional strategies specific to construction that agencies can use to aid in integrating substantive safety into construction activities.

The following sections detail the applications of substantive safety in construction. See the tables in the appendix for more information about substantive safety principles and safety effects associated with various design elements considered during project development. Table 6-2 provides similar information that is about the various construction and work zone strategies presented in this chapter and that can be used for quick reference by the construction professional during ongoing construction activities.

Table 6-2. Construction and Work Zone Strategies

Temporary traffic control and work zone management plan	• The purpose is to anticipate and describe the traffic control measures needed during project construction and to outline coordination needs with owner agencies and the public, particularly to ensure safety. • The construction staff needs to be aware of the safety implications of changes to design and to coordinate with people who made the original decisions on the design details. • Safety analyses can and should be conducted to ensure that the safety features incorporated into the design of the project are being maintained. • The same principles of safety in the design of the permanent facility can be applied to the roadway facility during construction. • Substantive safety knowledge will provide valuable guidance on selecting and applying safety countermeasures in work zone design to proactively mitigate known work zone safety issues. • Analysis of crash trends in work zone conditions can help identify and diagnose work zone safety issues as they develop. • Trend analysis on a program level can help an agency assess how well its work zones are operating, can aid in developing and managing work zone safety programs, and can guide improvements in work zone safety performance and management.
Manual on Uniform Traffic Control Devices (MUTCD)	• The guide is provided to set up proper work zone traffic control. • It provides the recommended practice for advance warning for drivers approaching the work zone and the use of traffic control devices for guiding traffic safely through the work zone.
Accommodation of pedestrians and bicycles	• Temporary facilities must be provided so that pedestrians are not guided through the work area or into traffic. • The construction zone changes frequently, adding to the challenge of maintaining a safe path for pedestrians. • Barriers or fences should also be provided to keep pedestrians out of the work area. • It may be necessary to install a temporary crosswalk at each end of the project and to require pedestrians to cross the road and use the sidewalk on the other side to detour around the work zone. • Bus stops or pedestrian access to adjacent properties may have to be relocated temporarily. • Existing bicycle facilities should be maintained through or detoured around the construction zone. • If enough paved lane width cannot be maintained for vehicles to pass bicycles safely, it may be advisable to set up a detour route for bicyclists.
Construction road safety audit (RSA)	• Work zone RSA focuses on the work zone design, operations, and safety. • An RSA of changes in design during construction is normally conducted only when a substantial change in the design happens during the construction phase of the project development process. • The preopening RSA is the last opportunity for the owning agency to make safety improvements before opening the facility to traffic. It may also point out incorrectly located or poorly installed features, such as poles, barriers, and other safety devices, and temporary obstructions that were overlooked during site cleanup. • Sometimes, those minor changes can reduce safety risk at minimal cost.
Performance monitoring and evaluation	• Consideration of substantive safety in the development of work zone performance monitoring and evaluation will help agencies improve their decision making regarding work zones. • A data-driven analytical process for monitoring and evaluating the safety performance of work zones is critical to the successful application of substantive safety concepts during construction.

Table 6-2. Construction and Work Zone Strategies *(continued)*

Tool or Best Practice for Construction	Impact on Safety
Transportation/Traffic Management Plan	• The development of the Traffic Management Plan involves putting together a strategy to guide traffic safely through the construction project area. • FHWA encourages agencies to consider temporary traffic control early in the design process so that additional strategies can be assessed when making revisions to the design is still possible.
Emergency assistance and incident management	• Emergency vehicle access points may need to be used during construction. • Keeping equipment located where it can be readily implemented to respond to incidents will reduce response time on large freeway projects. • Service patrol vehicles equipped to help repair disabled vehicles or to move them from the travel lanes will quickly help reduce congestion and additional crashes caused by the queuing of vehicles following the incident.
Work zone (law) enforcement	• Enforcement includes activities undertaken by police officers to enforce laws and to encourage safe conditions in work zones. • Law enforcement should be used where speed reduction and awareness of work zones are not being adequately accomplished with signing and work zone channelizing devices. • Automated speed enforcement may be used in confined and high-speed work zones; however, the laws in some States do not allow automated enforcement. • The most common use of law enforcement officers during construction is for visible enforcement of speed limits through the work zone and for more orderly merging where the number of lanes through the work zone is reduced. • All States increase the penalty of certain traffic offenses, usually speeding, that occur in work zones. Some States also increase the penalty for traffic violations related to incident clearance within a work zone.
Worker safety and visibility training	• The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) provides authority for States to use funds from five primary core programs to support training, education, and workforce development regarding worker safety in construction work zones. • SAFETEA-LU can be used to provide roadway safety training courses, such as safety training for traffic control technicians and traffic control supervisors.
Intelligent transportation systems tool	• A variety of technologies exist to monitor, evaluate, and manage transportation systems to enhance efficiency and safety. • Providing real-time traffic and lane closure information can enable drivers to choose alternate routes and transportation modes, thereby reducing travel times and delays caused by incidents as well as reducing secondary incidents. • Dynamic no-passing zone systems use a series of signs that display the message "Do Not Pass When Flashing" to expand the length of the no-passing zone and to direct vehicles to change lanes before the point of congestion to avoid abrupt last-minute lane changes. • Speed limit changes in the work zone are noted by flashing regulatory signs, radar speed-display units, and increased law enforcement presence.
Safety Edge℠	• The edge of the roadway is shaped at an angle of roughly 30 degrees from the pavement cross slope during the paving process, which mitigates pavement edge–related crashes and eliminates "tire scrubbing" that can occur when the driver attempts to recover after the tire leaves the pavement surface.
Temporary traffic barriers	• Temporary barriers provide motorists with guidance and protection from dropoffs, equipment, or other fixed objects. • Temporary barriers protect workers in the work zone from errant vehicles and protect the occupants of errant vehicles from fixed objects, dropoffs, and other hazards within the work area. • Temporary concrete barriers and water-filled barriers are examples.
Portable or temporary rumble strips	• Transverse rumble strips can alert drivers to the changing conditions and to the information being provided by temporary traffic control devices. • Rumble strips provide both an audible warning and a physical vibration to alert motorists as the vehicle tires traverse the rumble strips. • Rumble strips can be used to alert motorists to such conditions as lane closures, speed reductions, changes in alignment, new merge patterns, visual obstructions, nighttime work zones, and other conditions that motorists would not expect to encounter.
Total road closure	• Motorists or workers are not exposed to work zone hazards if no traffic travels through the construction zone. • A road closure requires additional travel on alternate routes.
Consistency in traffic control and pavement markings	• Consistent traffic control conveys necessary information to drivers despite changes from one stage of construction to the next. • Pavement markings guide drivers through the work zone. Temporary pavement markings are often difficult to see in wet or bright sunlight conditions. • Proper obliteration of permanent, conflicting markings is an important issue. Incomplete removal of old pavement markings can lead motorists to drive out of the intended lane through the work zone.

6.4 TOOLS AND RESOURCES FOR INTEGRATING SAFETY INTO CONSTRUCTION

The tools discussed earlier in this report can be used to evaluate the substantive safety and cost-effectiveness of many geometric and traffic control improvements. Tables 4-4 and 5-2 should be consulted for the tools for planning for systematic safety improvements and quantifying substantive safety effects of design elements that can be similarly applied to the construction. Table 6-2 summarizes tools and best practices for applying substantive safety in construction, as noted throughout this chapter.

Several other tools mentioned in chapters 4 and 5 have benefits specific to construction activities worthy of noting that agencies can use to aid in integrating substantive safety considerations into construction.

AASHTO *Highway Safety Manual*—With recent research and the development of statistical models, it is now possible to evaluate the effects of changes in design criteria on the expected safety performance of a project under design. Part C of the HSM contains methods and tools that can be used to predict the frequency of crashes on the roadway section for normal conditions but that cannot yet be used to estimate the change in crash frequency for those same criteria during construction.

The HSM provides two work zone design treatment CMFs: one for duration in number of days and the other for the length of the work zone in miles. The expected average crash frequency effects of increasing work zone duration and length are estimated using functions. The standard error for both CMFs is unknown.

CMF Clearinghouse—FHWA's CMF Clearinghouse contains additional work zone CMFs with ratings of three stars or more. They include (a) active work with no lane closure, (b) 1-foot increase of the inside shoulder width inside the work zone, and (c) implementation of left-hand merge and downstream lane shift. Information about work zone research projects can be found on the National Work Zone Safety Information Clearinghouse's website (http://www.workzonesafety.org/research).

Part D of the HSM and the CMF Clearinghouse both have CMFs for use in estimating some effects of work zones on crash frequency. The HSM contains CMFs for duration and length of work zones, and the CMF Clearinghouse contains other limited CMFs. The increase in crashes because of the presence of a work zone is predicted by applying CMFs in Part D to the estimated crash frequency for a work zone on the basis of historical trends.

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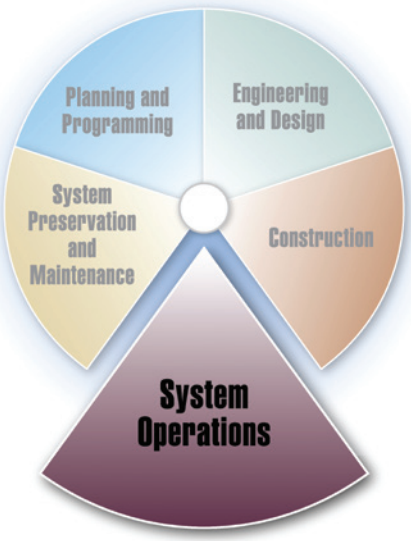
TRANSPORTATION SYSTEM MANAGEMENT AND OPERATIONS

7

Photo courtesy of Thinkstock.

Figure 7-1. System Operations in the Project Development Process



Source: CH2M HILL.

7.1 INTRODUCTION

Transportation system management and operations (TSM&O) is the frontline of a transportation system (see figure 7-1). It is one of the areas that is most visible and noticeable to the traveling public—possibly second only to resurfacing, restoration, rehabilitation (3R) projects for public visibility. Likewise, TSM&O forms the core of how the traveling public interacts with the travel environment—for all modes of transportation. By its very nature, TSM&O presents numerous opportunities to address safety performance through the integration of substantive safety.

Daily decisions in TSM&O are often made in the belief that they are improving the "safety" of the road. That belief may very well be true. For many safety strategies, the science of traffic safety has progressed to a point where the operations staff can look to numerous resources and can have a quantitative understanding of the expected safety performance, rather than simply believing that "safety will happen."

That approach does not mean that incorporating substantive safety into transportation projects is simple or straightforward. Clearly, one key factor is providing the operations staff with resources and information about safety strategies and their performance. However, one area that may often be overlooked is establishing a process for the operations staff to provide input and value to other divisions of the agency.

The importance of safety performance is often undervalued in TSM&O decisions. This chapter has the following objectives:

- Identify approaches that agencies can use to make decisions in the operation of their roadway system that provide a safety benefit.
- Help agencies make greater use of substantive safety information to inform the decision-making process.

For example, if an agency adds a left-turn lane at an intersection, what is the expected safety benefit? Likewise, what is expected when pedestrian countdown signals are installed?

7.2 OVERVIEW OF TSM&O

The definition of TSM&O is very broad, but the intent is to encourage and promote the safe and efficient management and operation of integrated, intermodal surface transportation systems. For this report, it is important to understand that the definition of TSM&O does not include maintenance activities (such as plowing after a snowstorm) or pavement maintenance. A key element to understanding the difference between the two is that maintenance relates to maintaining a state of good repair, whereas TSM&O is focused on managing the traveling public.

That distinction recognizes that TSM&O is defined by the context of the roadway or facility. Considering that although the context of each roadway or project is defined by the area within which it is built, the design principles are often applied consistently across common roadway types. However, the facilities may include other modes of travel, such as walking, bicycling, and transit that require differing approaches to operations. Operations also need to consider whether the surrounding land use requires support of a certain vehicle type, such as industrial land use relying on oversize or overweight trucks to move specialty freight items.

Finally, it is important to recognize that the scope of operations varies by jurisdiction. For example, a rural county may have few facility types in its transportation system, with most of the system consisting of rural, two-lane corridors. Therefore, decisions regarding operations may be primarily about signing and pavement marking improvements, access management, and occasional location improvements, such as adding turn lanes. In contrast, the scope of operations for a city or urban county may cover those same topics but may also include signal operations and multimodal interactions. Furthermore, TSM&O for State transportation departments further expands to traveler information systems, incident management, and demand management.

Not all agencies operating both urban and suburban road systems will have the same priorities. Some urban and suburban areas may have a much larger pedestrian, bicycle, or transit commuter base, which makes related operations management a higher priority. Conversely, in urban and suburban areas where alternative modes are not commonly used, operational decisions may be focused on serving vehicular transportation. It is important to note that although the scope of operations may differ among facilities and jurisdictions, often requiring differing approaches to TSM&O decision making and management, that difference does not imply that an agency should make operational decisions that hinder lower-priority modes or make them less attractive.

7.3 APPROACHES TO OPERATIONS MANAGEMENT

An agency's organization, as well as its size, can create barriers that prevent the operations staff from implementing some types of improvements. The key is to recognize the barriers that prevent operations staff members—who may have the best understanding of the transportation system's actual performance—from providing meaningful input into planning and programming, asset management, and maintenance.

After one identifies barriers, opportunities to improve the process become evident. A possible example is that the selection and implementation of a solution may be outside the operations staff's ability to address through traditional operational activities, especially if the agency's organization means that operations personnel are not involved in planning, programming, or maintenance. For example, operations staff members may be the first to identify the need for a roundabout or turn lane improvement, but the scale of such an improvement exceeds their ability to implement it. That situation creates an opportunity to put in place a communications process whereby operations personnel provide input into the purpose and need identification of planning and programming.

Likewise, operations staff members may be in the best position to identify which focused improvements could be incorporated into basic asset management projects. A typical example is adding shoulder paving with rumble strips or guardrail updates to an overlay project that is part of a preventive maintenance program. In that scenario, the opportunity is to establish an asset management process that allows for review and comment by, and possibly direct input from, the operations staff.

There are also activities that bridge TSM&O and maintenance that might not align with operations, depending on the agency's organization. Such activities would not include larger projects, such as overlays, but would instead include smaller routine maintenance, such as striping; replacing missing, damaged, or worn signs; maintaining vegetation control; and repairing guardrails. In addition, systemic safety program projects,

which agencies may be able to implement as part of routine maintenance activities, are typically low cost and within the scope of the operations and maintenance budgets. Again, that approach suggests an opportunity to provide the operations and maintenance staff with a process to coordinate project ideas.

It is also important for dedicated traffic safety staff members to coordinate with operations staff members. When the traffic safety staff identifies priorities—crash types, facilities, or strategies—for the safety program, the operations division is a potential partner for helping implement countermeasures quickly and efficiently. It may also be able to provide input into the safety planning and analysis process by identifying needs and issues.

7.4 SUBSTANTIVE SAFETY CONSIDERATIONS IN TSM&O

7.4.1 Integration of Safety into TSM&O

For all agency types and regardless of the focus of the TSM&O division, typical activities for TSM&O often include the following:

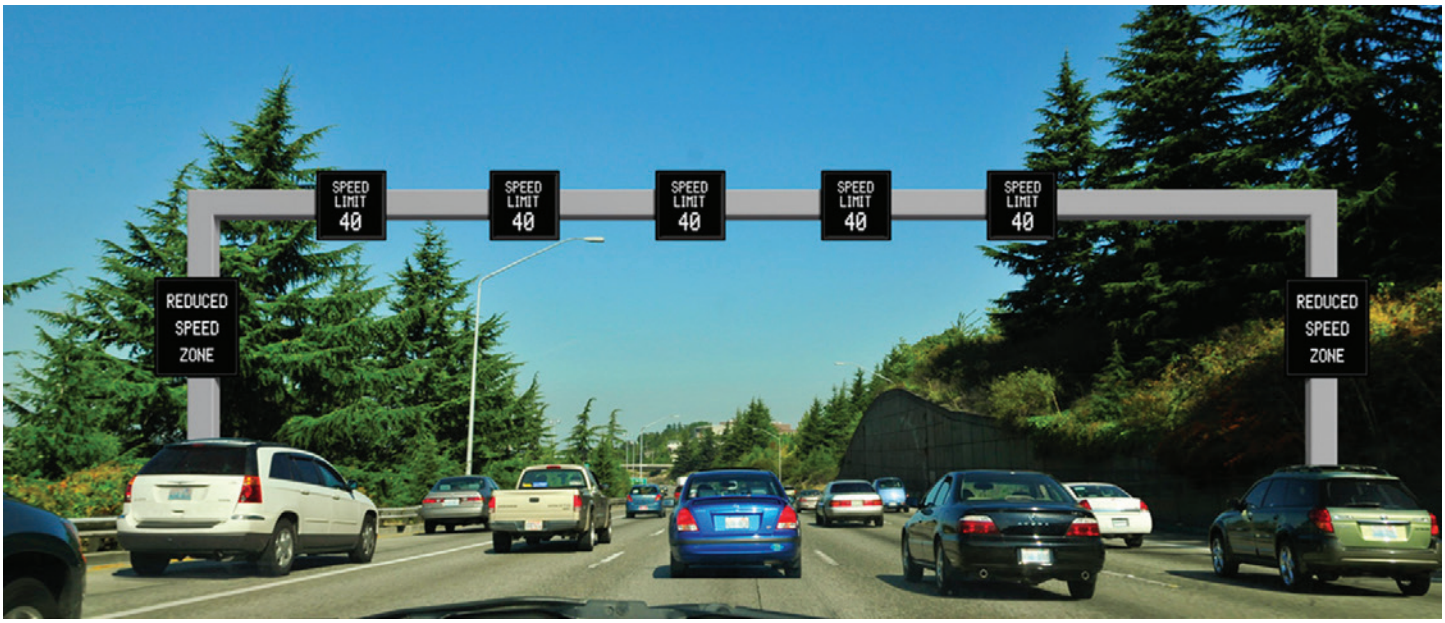
- **Safety Data Collection, Analysis, and Management**—Local and State agencies have a responsibility to collect both operational and crash data across their roadway systems. The Model Minimum Uniform Crash Criteria[1] and Model Minimum Inventory of Road Elements[2] were developed to create a national standard for data collection that allows information sharing across agency boundaries. However, many local jurisdictions—on the basis of the number of resources available to collect basic traffic and crash data—instead have used the best locally available safety tools, which may not conform to national-level guidelines. Fortunately, a greater number of data management systems are both computerized and maintained at a State level. They even include electronic crash reports that allow local agencies to collect and upload crash data to a statewide database. Many organizations have computerized their asset management systems (using a Geographic Information System, for example), thus increasing access to location-specific geometric and traffic information.
- **Development Review**—Review of development plans may address access management, improvements required to mitigate new trip generation, sidewalks, and/or other transportation improvements. During a review process, agencies can actively address traffic safety through either a proactive approach by recommending countermeasures or a reactive approach by identifying locations during network screening where adjacent development is affected.
- **Problem Identification and Diagnosis**—TSM&O often addresses a range of operational issues identified by elected or appointed officials, by the general public, by data review, or by personal observations when in the field. TSM&O may identify various needs or issues, which are often influenced by the agency's context. However, safety should be an explicit consideration during the process and should not limit the process to traffic operations. Despite the wide range of contexts across agencies, many strategies and countermeasures will work for a variety of situations. Tools and resources to aid with selecting appropriate countermeasures were reviewed in the project formulation step in chapter 4.
- **Countermeasure Development and Recommendation of Projects**—On the basis of need identification and diagnosis, the TSM&O division may consider a range of alternatives to solve a particular need. In the past, a typical process was to perform a benefit–cost analysis or an environmental analysis (or both) of the range of options and to present the options to management or the public. A typical process may not have explicitly considered or addressed safety, or looked at safety through a nominal perspective. (Does the solution meet standards?) But now, tools and resources exist that allow the process to quantitatively address safety (see chapter 5, section 5.3.2), as has been done with traffic operations and environmental issues.
- **Monitoring and Evaluation**—Following implementation, TSM&O is responsible for ongoing monitoring of the transportation system. Monitoring and evaluation provide critical information on actual performance and outcome, which influence future implementation. Safety performance needs to be part of that feedback cycle, thereby allowing TSM&O to make informed decisions. It is important to note that monitoring and evaluating safety performance can happen at the project level (determining the effect of individual projects) and at the system level (understanding overall trends in crashes, especially fatal and severe injury crashes). Making system-level safety a performance measurement will instill the need for individual commitments to integrating safety consideration into every action and decision.

7.4.2 Application of Substantive Safety to TSM&O

Given that operations activities vary greatly across jurisdictions and across agencies, a few examples for integrating safety into operations practices are provided. Although some best practices are presented within this section, certainly other examples exist. The following discussions focus on the areas of traffic operations, access management, multimodal operations, enforcement, and safety performance monitoring and evaluation.

For safety performance information regarding specific safety countermeasures (including those in the following discussion), refer to tables A-1 and A-2 in the appendix. Additional information regarding best practices for integrating safety is also provided in chapters 4 and 5. The information regarding best practices may prove useful to TSM&O when identifying the range of possible solutions and evaluating a preferred strategy.

Figure 7-2. Washington State DOT Variable Speed Limits



Source: Washington State Department of Transportation.

7.4.2.1 Traffic Operations

Operations of Corridors and Signal Timing. A commonly identified area for systems operations is the management of corridors and traffic signals. Approaches may range from implementing simple signing or pavement marking treatments for at-risk locations (from rural horizontal curves to urban pedestrian crossings) to managing advanced signal systems in urban areas.

A range of geometric treatments (for example, turn lanes and median closings) presents additional opportunities to improve safety performance. Typically, such treatments are easily implemented by the operations staff and may not require coordination across the agency to accomplish. However, a countermeasure may need further vetting before implementation, especially if it represents an innovative strategy that is new to the area.

The following are a selection of best practices:

- One- or two-way street operation is a consideration within a city where the blocks are small enough that reasonable access can be provided with one-way streets. That scheme would require some out-of-direction travel by motorists. The number of conflicts is reduced at intersections, resulting in safer and more efficient traffic signal operations, and is typically shown to reduce crashes. In some cases, one-way streets can result in higher overall operating speeds. If that speed were to occur, it may be necessary to provide mitigation treatments where there is a concentration of pedestrian or bicycle traffic.
- Signal coordination, timing, and phasing for vehicles must consider the volume and amount of turning traffic. More phases mean more lost time, so there are tradeoffs between the safety of protected phases and the efficiency of traffic flow. However, protected phases may produce safety benefits for left-turn movements and crossing pedestrians. Signal operation should include periodic reviews of signal timing plans (including clearance intervals) to determine if signals or corridors could operate more efficiently. Additional changes may include converting permissive left turns to flashing yellow-arrow signal indicators or operating signals in actuated mode instead of flash mode for late-night operations.
- Turn restrictions (24 hour, time of day) can help reduce conflicts, thereby increasing the safety and efficiency of traffic signal operations. Those restrictions can keep through traffic moving more smoothly on arterials and can discourage through traffic from cutting through residential local streets. However, compliance with turn restrictions may be an issue.
- Roundabout intersections reduce the severity and number of conflicts within the intersection and should slow vehicles, which has a demonstrated safety benefit. Their ability to keep traffic moving makes them more efficient than all-way stop-controlled intersections, especially where traffic is distributed so that gaps occur.

Demand and Incident Management. State departments of transportation and large cities have long used technology and programs to help manage and operate their freeway systems in order to maintain efficient operations.

Freeway management may include high-occupancy vehicle lanes, toll lanes, ramp metering, variable speed limits (see figure 7-2), bus shoulders, incident response teams, variable message signs (for travel time information or queue

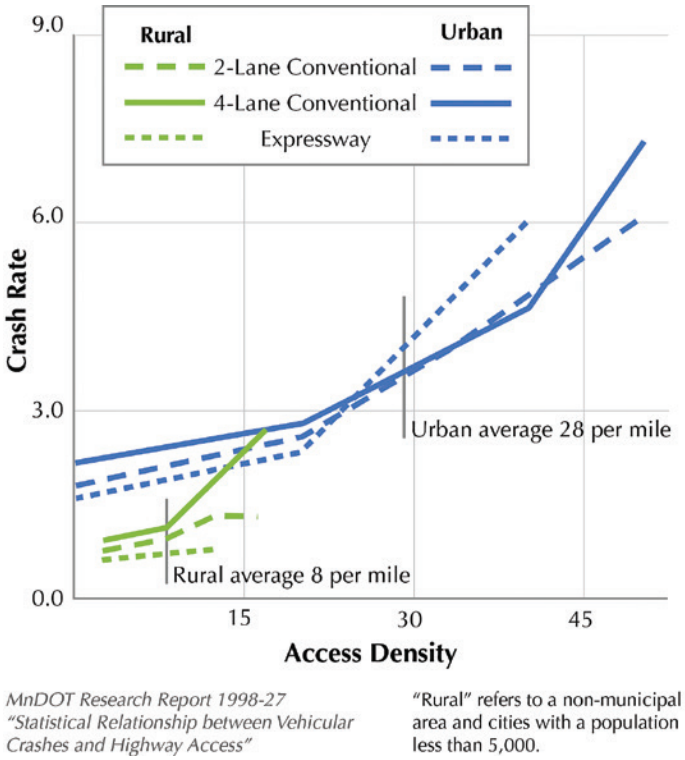
warning), and dynamic lane assignment (see figures 7-3 and 7-4). Because some of those strategies are not widely used across the country or are unstudied, little is known regarding their safety performance. However, when international experience is included, there is a good basis to believe that many operational strategies may improve safety performance. However, caution is needed. Some research indicates that a few strategies (such as hard shoulder running) may lead to an increase in total crashes but with a decrease in crash severity.

Traveler Assistance Technology. Technology is a growing part of operations. Many State departments of transportation have implemented traveler information systems (511 systems) to inform drivers about road surface conditions, construction, incidents, and travel time and speeds because of recurring events (normal peak-hour congestion) and nonrecurring events (special event, incident, or construction-related congestion).

Many large metropolitan areas also provide peak-period travel speeds and congestion maps. Since the inception of traveler assistance technology, access to such information has become easier for travelers. Most States began with fixed-location, changeable message signs and over time have added phone and text messages, Internet-based information, and eventually smartphone applications that provide timely access to traveler information. Expanded opportunities to access traveler information systems are anticipated to result in an increased use of the available information.

The intent of those systems is to provide drivers information about current conditions that can help them make informed travel decisions to avoid congestion or select the roads with the best surface conditions during adverse weather. From a safety perspective, the benefit is primarily twofold. First, by helping drivers choose corridors with the best driving conditions, or even potentially decide to forgo a trip because of road conditions, winter weather crashes may be reduced. Second, by providing drivers with information that may encourage them to select alternative routes, the demand on congested routes (because of recurring delay, construction, or incident) may be reduced. Reduced demand in congested corridors is expected to reduce the number of secondary incidents that can occur in stop-and-go driving conditions, including severe crashes that can occur when free-flowing vehicles encounter traffic that is backed up.

Figure 7-3. Minnesota Roadway Segment Crash Rates as a Function of Facility Type and Access Density



Source: Minnesota Department of Transportation, Traffic Safety Fundamentals Handbook.

Figure 7-4. Minnesota DOT Smart Lanes

Source: Minnesota Department of Transportation.

7.4.2.2 Access Management

The operations staff is often involved in reviewing access requests. Access control has been demonstrated to be an important part of safety performance for rural and urban facilities.[3] *The Highway Safety Manual*'s predictive models for urban and suburban arterials use the number and type of driveways as direct input in predicting the total number of crashes in a corridor.[4]

If such is not already in place, agencies should consider developing access management guidelines. Agencies may also need to review older access management plans to see if they are current with the latest research. For agencies and individuals unfamiliar with access management principles, the

Figure 7-5. HAWK Signal in Phoenix, Arizona

Source: www.pedbikeimages.org/ Mike Cynecki.

Figure 7-6. Bike Lane in Santa Cruz, California

Source: www.pedbikeimages.org/ Bill Daly.

Transportation Research Board's *Access Management Manual* may be a good starting reference.[5]

7.4.2.3 Multimodal Operations

A growing safety interest in the area of multimodal transportation is eliminating, reducing, or minimizing the conflict between pedestrian, bicycle, and transit modes and passenger vehicles. The operations staff can implement various projects that may accomplish those goals.

The following are examples of project types:

- Evaluation of signal timing and of phasing that will minimize conflicts between pedestrians and vehicles, such as protected left turns to eliminate conflicts between left-turning vehicles and pedestrians. Pedestrian phasing or a leading pedestrian interval may be an effective treatment in areas with high pedestrian volumes. Countdown timers are widely used; their intent is to reduce the number of pedestrians in the road when the signal phase changes. Operations managers should also consider the typical population in an area when selecting walk speeds for determining pedestrian times. In areas where the pedestrians are often children or the elderly, longer walking and clearance times might be needed.
- Implementation of traffic-calming techniques in a residential area or business district with significant through traffic or high pedestrian and bicycle volumes. Some countermeasures, such as curb extensions or median refuge islands, may serve the dual purpose of calming traffic and minimizing crossing distances for pedestrians.
- Implementation of mid-block crossings with high-visibility treatments are effective where no grid system provides for efficient pedestrian movements. Some treatments to increase the safety of pedestrian crossings include rectangular rapid-flashing or pedestrian hybrid (also known as High-intensity Activated crossWalK, or HAWK) beacons (see figure 7-5). Those treatments have been shown to be effective at increasing the yield rates of drivers to pedestrians and bicycles.
- Addition of a bicycle lane (see figure 7-6) where possible when a corridor is being restriped as part of a road diet. In corridors where bicycle travel is not advised because of high speed or a large number of heavy vehicles, bicycle boulevards on a parallel street instead of a bike lane in the undesirable corridor may provide better safety performance.
- Signal operations, especially at transit service locations, that have a timing plan to minimize the interaction between pedestrians, transit vehicles, and passenger vehicles. Some agencies have used pedestrian scramble phases near transit centers because of the concentration of pedestrian activity.
- Placement of bus stops to minimize effects on vehicle travel and to allow buses to easily merge back into the traffic stream. Additionally, determining where to place a bus stop can consider significant origins or destinations for transit riders. Bus stop placement can minimize the number of street crossings between the bus stop and the destination. That approach reduces conflicts between pedestrians and vehicles, thereby reducing crashes.

Part of the challenge is determining those areas that are best suited for such treatments. In general, areas with the greatest concentration of pedestrians or bicycles will have the greatest potential for crashes. They may include commercial areas, schools and colleges, downtown districts, parks, bus stops, transit routes, and transit centers. In those situations, a Complete Streets project may help identify preferred treatments.

7.4.2.4 Enforcement

Highway agencies often overlook the important support role they play in traffic enforcement. Properly setting and posting

speed limits in corridors can minimize speeding and other driver behaviors that bring about the need for law enforcement. Another traditional solution that supports traffic enforcement is to provide safe areas for officers to make traffic stops. Roads with narrow shoulders, especially high-speed roads, can endanger officers while outside their patrol vehicles. Instead of widening shoulders along the entire corridor, a lower-cost option is to work with law enforcement to identify locations where pullout areas could be constructed.

Installing speed feedback signs, confirmation lights, and automated enforcement (using cameras to enforce traffic safety laws) is another way for the operations staff to support traffic enforcement. Speed feedback signs, whether portable or fixed, can be deployed with input from law enforcement to address areas where speeding is common. Similarly, sites for confirmation lights, which allow for more effective traditional red-light-running enforcement, should be selected with input from law enforcement officers. Ideally, both strategies will have a commitment from the law enforcement agency to perform periodic speed or red-light-running enforcement in the area.

Another area in which the operations staff can support law enforcement agencies is the deployment of automated enforcement. As with speed feedback signs and confirmation lights, automated enforcement should be used in coordination with law enforcement agencies. Their input, as a support to crash or violation data, gives greater confidence to motorists that the technology is about reducing crashes and improving safety performance rather than about revenue generation. Information about the use of automated enforcement for red-light violations is available at FHWA's Red-Light Running webpage (http://safety.fhwa.dot.gov/intersection/redlight/).

7.4.2.5 Safety Performance Evaluation: Continuous Process Improvement

Monitoring safety performance is an important part of TSM&O for any facility. The key is to be able to compare actual crash occurrences with either predicted or expected values (such as average crash rate, average crash frequency and density, or predicted crash frequency) to identify locations where safety performance indicates a potential need for improvement. Additional information regarding safety evaluation techniques is provided in chapter 5, section 5.3.2.

To produce reliable analyses of safety performance, agencies must maintain accurate and timely crash information, including location information, which allows for the identification of the number and severity of crashes that occur at an intersection, along a corridor, within a curve, at a railroad crossing, and so forth. Those assessments can rely on total crashes. However, serious crashes (those resulting in one or more fatalities or incapacitating injuries) deserve special attention to ensure that efforts do not overfocus on property damage crashes. If an agency has not selected a method to assess safety performance of individual elements, Part B of the *Highway Safety Manual* lists various methodologies that can be used to assess safety performance and provides the advantages and disadvantages of each evaluation method.

Because the operations staff has firsthand knowledge of the actual safety performance of the road system, it has an opportunity to provide feedback as a continuous improvement process within the agency. As noted, agencies are encouraged to have the operations staff provide input into planning and programming, asset management, maintenance, and safety planning to identify needs and to develop countermeasures. However, a second aspect of that communication is for the operations staff to provide feedback on the performance of implemented projects. That feedback can range from sharing which geometric conditions are considered as contributing to crashes to which countermeasures have not performed as intended—and why—and which countermeasures have resulted in the desired outcome. By sharing such information, the departments responsible for those areas can avoid creating situations that may result in a future issue and can instead migrate toward situations and ideas that have proved effective at preventing or reducing crashes.

7.5 TOOLS AND RESOURCES FOR INTEGRATING SAFETY INTO TRANSPORTATION SYSTEMS MAINTENANCE AND OPERATIONS

Many resources that are available to the operations staff are described in previous chapters. They include the Crash Modification Factor Clearinghouse,[6] the *Highway Safety Manual*,[7] and the National Cooperative Highway Research Program's *Report 500*,[8] *Report 600*,[9] and *Report 622*.[10] Each resource contains example strategies that can be applied to improve the safety performance of an area, corridor, or intersection. They also include processes and checklists to help select strategies according to crash patterns, as well as expected changes in crash frequency on the basis of research.

Additional resources include websites dedicated to context sensitive solutions,[11] to Complete Streets,[12] and to pedestrians and bicycles.[13] Websites post such information as process guides, technical reports, case studies, webinar opportunities, and images. All those resources may help the operations staff understand where opportunities exist to enhance safety and the types of new countermeasures that are available.

Several new design-related guides also exist for urban areas, including the National Association of City Transportation Officials' *Urban Bikeway Design Guide*[14] and *Urban Street Design Guide*[15] and the Institute of Transportation Engineers' *Context Sensitive Solutions in Designing Major Urban Thoroughfares for Walkable Communities*.[16] Those guides provide processes and solutions that cities are implementing with the goal of meeting the needs of the traveling public safely and efficiently.

7.6 REFERENCES

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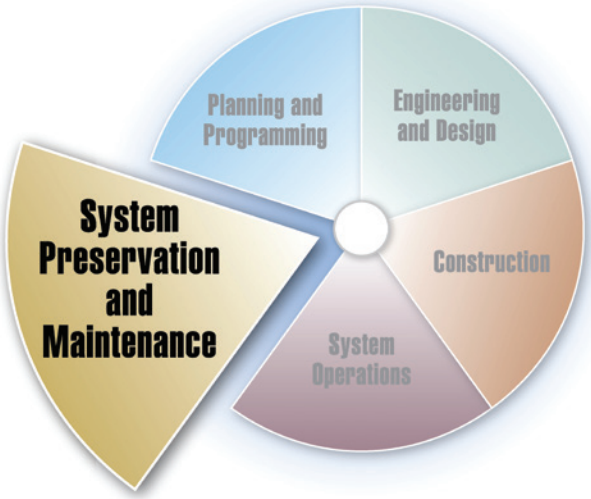
SYSTEM PRESERVATION AND MAINTENANCE

8

Photo courtesy of Thinkstock.

Figure 8-1. System Preservation and Maintenance



Source: CH2M HILL.

8.1 INTRODUCTION

The preservation and maintenance of transportation assets are a high priority for agencies. Preservation and maintenance of transportation systems protect the public investment and are vital in maintaining safety and efficiency along an agency's roadway facilities. Agencies continuously balance the needs of maintaining transportation system assets with other needs. For example, they allocate resources among new geometric and reconstruction projects and projects needed to maintain and preserve the existing infrastructure. However, although the project need may differ between new construction or reconstruction and system preservation, the need to provide safe and efficient transportation facilities does not.

The system preservation and maintenance (SP&M) phase is one of the final activities in the project development process (PDP) (figure 8-1). From the standpoint of substantive safety management, it embraces a number of project types that will help reduce overall crash potential. Project types include resurfacing, restoration, and rehabilitation (3R), as well as maintenance.

Those types of projects and activities focus on the preservation and management of assets—transportation asset management. As defined by the American Association of State Highway and Transportation Officials' (AASHTO's) Subcommittee on Asset Management, transportation asset management is

> *… a strategic and systematic process of operating, maintaining, upgrading and expanding physical assets effectively through their life cycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well defined objectives.*[1]

Safety activities in the SP&M phase focus on (a) evaluating roadway performance, (b) identifying needs and opportunities for near-term maintenance and improvements to the system, (c) implementing improvements to the existing network, and (d) evaluating the effectiveness of past projects. Those activities naturally connect back to planning and programming in the life-cycle loop for a transportation facility that will lead to subsequent improvements over time to preserve or further improve functionality.

SP&M projects may span the full project development process from project idea to implementation and may include planning, design, and construction activities. Many of the fundamental steps of the project in the SP&M phase are the same as those presented in chapters 4 and 5, and those chapters should be consulted regarding the general process and procedures for the planning and design of an SP&M project. However, the special nature of those project types, as well as of some activities outside the normal transportation PDP, justifies addressing them in a separate chapter of this report.

This chapter has the following objectives:

- Describe what the role of safety in system preservation and maintenance is and how safety is incorporated into this phase, including monitoring performance, determining what needs to be done, and integrating safety into the SP&M program.
- Provide a better understanding of where substantive safety can be implemented within the SP&M phase of the PDP.

8.2 OVERVIEW OF SYSTEM PRESERVATION AND MAINTENANCE

Maintaining the structural integrity, functionality, and efficiency of the transportation system is a responsibility that agencies take very seriously. For 3R and maintenance projects, the focus is on the preservation and extension of the service life of facilities and the actions necessary to keep a highway facility in good condition.

Typically, 3R project types consist of (a) resurfacing, (b) pavement structural and joint repair, (c) minor lane and shoulder widening, (d) minor alterations to vertical grades and horizontal curves, (e) bridge repair, and (f) removal or protection of roadside obstacles. Typical maintenance activities include (a) improvement of pavements, roadside elements, and bridge facilities with associated projects, which may include repainting lane and edge lines; (b) removal of accumulated debris from drainage inlets; (c) repair of surface roadside and drainage features; (d) mowing; and (e) snow removal.

8.3 SUBSTANTIVE SAFETY CONSIDERATIONS

8.3.1 Integration of Substantive Safety into System Preservation and Maintenance

Road surfaces with rutting, major distresses (such as potholes), or low skid resistance can adversely affect traffic safety. Pavement repair, resurfacing, and rehabilitation activities that correct those conditions reduce the likelihood of crashes related to road surface conditions. Bridge maintenance and rehabilitation, incorporation of safety devices (guardrail, safety edge), and minor drainage improvements (culvert extensions) along the roadside keep important safety features (such as bridge railings) in good repair and reduce risks of structural failure.

Generally, SP&M activities have focused heavily on bridges and pavements. Other considerations, such as drainage, traffic signals, and rest areas, have also often been included in an agency's maintenance and asset management activities. The types of safety improvements more commonly included in 3R and some maintenance projects are as follows:[2]

- **Geometric**—Improve superelevation, minor widening, intersections, turn lanes, and acceleration and deceleration lanes; extend culverts.
- **Shoulder and Roadside**—Add shoulders, upgrade shoulders, widen shoulders, add rumble strips, add safety edge, increase clear zone, remove fixed objects, add guardrail or guide rail, and flatten slopes.
- **Traffic Control and Guidance**—Install signs, signals, delineation, markings, and rumble strips.
- **Surface Conditions**—Resurface, grind, and repair pavement joints and repair shoulders.

> **The fact that new design values are presented herein does not imply that existing streets and highways are unsafe, nor does it mandate the initiation of improvement projects.… For projects of this type (resurfacing, restoration, or rehabilitation [3R]), where major revisions to horizontal and vertical curvature are not necessary or practical, existing design values may be retained.**
> ***—A Policy on Geometric Design of Highways and Streets***

Improving sight distance either by eliminating or reducing sight restrictions or through geometric improvements, access management, and lighting will also have safety benefits that are frequently included in 3R activities.

Although some maintenance activities fall outside the requirements of the traditional project development process, agencies are increasingly including minor roadway and safety improvements as part of their annual maintenance program. SP&M projects span the full project development process, from project idea to implementation, and they include planning design and construction activities.

Chapters 4, 5, and 6 present opportunities focused on integrating substantive safety into all types of transportation projects (new, reconstruction, 3R, and maintenance), including valuable tools for use in SP&M projects. The same data-driven and science-based methods detailed in those chapters can be used to identify opportunities for improvement, to assess the safety effects of SP&M activities, and to supplement system monitoring. Many activities can be quantified by applying the same quantitative safety tools and resources, which are scaled to fit the project specific needs.

8.3.1.1 Design Controls, Criteria, and Standards

The primary difference between 3R projects and new construction and reconstruction is in the application of design criteria. The Federal Highway Administration (FHWA) and State departments of transportation generally acknowledge that AASHTO's Green Book[3] criteria do not always have to be adhered to for those projects. The passage of the Intermodal Surface Transportation Efficiency Act in 1991 permitted States to develop highway standards that were not centered on the Green Book criteria. As a result, most agencies have developed specific geometric design standards or guidelines for 3R projects, or both, and maintenance plans that differ from the design standards or guidelines used for new construction. Different agencies have various practices regarding geometric design criteria for 3R projects.

The Transportation Research Board's (TRB's) *Special Report 214: Designing Safer Roads—Practices for Resurfacing, Restoration, and Rehabilitation*[4] contains practices that can help agencies achieve safety objectives on 3R and maintenance similar to the minimum design criteria for new construction or reconstruction.

The following are key best practices:

- **Wider Driving Lanes and Shoulders—**Crash frequencies are lower as lane and shoulder widths increase, particularly on rural roadways. Roads with stabilized shoulders usually have lower crash frequencies than those without. Wider shoulders help increase safety for bicyclists and pedestrians.
- **Horizontal Curve Improvements—**Crash frequencies are higher on curves than on tangent segments of roadway. Although a clear relationship exists between horizontal curves and crash frequency, the cost-effectiveness of reconstructing horizontal curves can vary according to the project context and safety performance. In fact, most agencies do not have well-defined guidelines for horizontal curve reconstruction on 3R projects. Cost-effectiveness is normally determined on a case-by-case basis.

  Some guidelines in TRB's *Special Report 214*[5] allow for evaluation of the reconstruction of horizontal curves when the design speed of the existing curve is more than 15 miles per hour below the running speeds of approaching vehicles and when the average daily traffic volume is greater than 750 vehicles per day. If the superelevation rate is less than the maximum used in that region, increasing it may be a cost-effective treatment and an alternative to curve flattening. Agencies may also consider other crash mitigation strategies, such as advance warning signs, in-pavement warning devices, and increased enforcement (law, automated) as options for treating horizontal curves with safety issues.
- **Sight Distance Improvements—**Roadway sections with sight distance restrictions tend to have safety issues. Strategies for improving sight distance include both geometric and behavior considerations. The FHWA's *Mitigation Strategies for Design Exceptions*[6] states that strategies to mitigate sight distance issues should focus on eliminating sight restrictions, improving driver awareness, and improving a driver's ability to avoid crashes.
- **Roadside Improvements** (slopes, clear zones, and safety features)**—**Purchasing right-of-way to provide a greater clear zone distance or constructing a storm sewer system to replace open ditch drainage that has steep slopes will reduce the number of crashes that occur within the roadside area. Roadside safety features, such as barriers, crash attenuators, and breakaway poles, reduce the severity of crashes that occur when vehicles inadvertently leave the roadway. Roadway improvements (such as flattened curves, wider lanes, and paved shoulders) that make it less likely that a vehicle will leave the road are also considerations. A benefit–cost analysis should be used to determine where the agency's funds should be spent to get the greatest safety benefits from those roadside features. The benefit–cost analysis should consider the potential number and severity of crashes and the cost to construct and maintain the facility for the design life of the project.
- **Intersections and Traffic Control—**When planners are developing a maintenance improvement project, they should evaluate the intersections and traffic control within the project limits. At existing signalized intersections, the timing should be evaluated to determine whether operations could be improved with the existing equipment. In addition, other small improvements may be needed. Adding or extending a turn lane can greatly improve operation of an intersection. Installing a traffic signal to replace stop sign control may provide significant increases in capacity and safety of the intersection operation.

8.3.1.2 Adverse Weather and Ongoing Maintenance Activities

Adverse weather (such as visibility impairments, precipitation, high winds, and temperature extremes) can affect driver capabilities, vehicle performance (such as traction, stability, and maneuverability), pavement friction, roadway infrastructure, crash risk, traffic flow, and agency maintenance productivity.[7]

Most weather-related crashes happen on wet pavement and during rainfall events. National crash averages for 2002 to 2012 show that 74 percent of crashes occurred on wet pavement and 46 percent during rainfall. During the period, a much smaller percentage of weather-related crashes occurred under winter conditions: 17 percent occurred during snow or sleet events, 12 percent on icy pavement, and 14 percent on snowy or slushy pavement. Only 3 percent of weather-related crashes occurred in the presence of fog.[8]

8.3.2 Application of Substantive Safety to System Preservation and Maintenance

The tools discussed previously can be used to evaluate the substantive safety and cost-effectiveness of many geometric and traffic control improvements. Chapters 4 and 5 should be consulted in planning for systematic safety improvements and quantifying substantive safety effects of design elements that can similarly be applied to the planning, engineering, and design of 3R and maintenance projects. Several tools mentioned in those chapters have benefits that are specific to SP&M activities and that are worthy of note. The following subsections detail the applications of substantive safety to SP&M.

8.3.2.1 Diagnosis, Crash Analysis, and Countermeasure Development

When one is applying substantive safety principles to SP&M, it is not always feasible or practical to meet current standards for new construction. Identifying specific and cost-effective safety improvements requires consideration of infrastructure and crash data. Crash data analysis from the systemic perspective (chapter 4), which is also location specific and relative to the specific project design (chapter 5), can aid in targeting selected safety improvements to be incorporated into SP&M activities on either a programmatic or project level. The predictive methods in Part C of the *Highway Safety Manual*[9] can be used to combine safety performance functions for categories of roadways and targeted safety improvements and the observed accident frequencies into a single estimate of the expected accident frequency. Alternatively, the simpler crash modification factor approach can be applied to estimate the effects of various safety treatments (countermeasures) or roadway features regarding their ability to reduce crashes.

8.3.2.2 Road Safety Audit Reviews

Maintenance projects are often ideal candidates for a road safety audit review (RSAR), which is a version of a road safety audit (RSA) performed on existing facilities. An RSAR is "an evaluation of an existing roadway section by an independent team, again focusing solely upon safety issues."[10] The multidisciplined RSAR team will usually recommend low-cost features that can be added to projects of limited scope to improve safety. Some low-cost improvements are additional pavement markings, rumble strips, barrier improvements, signing, traffic control items, minor slope flattening, and shoulder and lane widening. Improvements such as slope flattening also have the benefit of reducing maintenance costs.

RSAs at the different phases of project development are conducted in the same format. The focus just varies to ensure that the suggested improvements can feasibly be added to the project scope. *Synthesis 336: Road Safety Audits*[11] provides prompt lists and guidance for conducting RSAs, including RSARs on existing roadways. (For additional information, see the FHWA webpage on safety, http://safety.fhwa.dot.gov/rsa.)

8.3.2.3 Roadside Safety Analysis Program

The Roadside Safety Analysis Program (RSAP) is a tool developed under the National Cooperative Highway Research Program's (NCHRP's) Project 229 for analyzing the benefits and costs of installing roadside safety devices. It is distributed with AASHTO's *Roadside Design Guide*.[12] The program implements the cost-effectiveness analysis procedure in chapter 2 of the *Roadside Design Guide*. The data needed to use RSAP include traffic, highway characteristics, alternative design information, and agency costs. The crash cost of each alternative is determined by (a) estimating the encroachment frequency of homogeneous segments of a project, (b) adjusting the encroachment frequency to account for variations from base conditions, (c) determining the probability of encroachments' resulting in roadside crashes, and (d) determining the likely crash cost of the roadside crashes.[13]

8.3.2.4 Access Management

Access points are locations of potential conflict. Access management seeks to improve traffic distribution, to reduce vehicle conflicts, and to reduce crashes by providing better access control. Better access control can be achieved by combining, reducing, and improving safety elements of access points. At-grade intersections and property access design techniques can be used to eliminate or manage conflicts. The result is a roadway that functions safely and efficiently for its useful life and that creates a more attractive corridor.

A good access management plan can offer a great combination among operation, geometric design, and safety. The FHWA report *Good Practices: Incorporating Safety into Resurfacing and Restoration Projects*[14] lists the following access improvements that can be included in 3R and maintenance activities to improve safety through access management:

- Intersection reconfiguration (horizontal and vertical realignment)
- Commercial entrance consolidation
- Commercial entrance reconfiguration
- Farm drive consolidation
- Farm drive reconfiguration
- Lighting
- Safety dikes[15]

The effects of many of those safety treatments can be quantified using the methods defined in chapter 5.

> **The fact that new design values are presented herein does not imply that existing streets and highways are unsafe, nor does it mandate the initiation of improvement projects.… For projects of this type (resurfacing, restoration, or rehabilitation [3R]), where major revisions to horizontal and vertical curvature are not necessary or practical, existing design values may be retained.**
>
> ***—A Policy on Geometric Design of Highways and Streets***

8.3.2.5 Transportation Asset Management

Asset management pertains not only to making investment decisions at a policy or program level but also to preserving highway network assets. The critical information on an agency's assets, including condition, can be collected during the SP&M phase of a project or roadway. Highway safety information needs to be included in a State's asset management program, along with pavements, bridges, operations, maintenance, and so forth, to help ensure optimal usage of limited available funding. To accomplish that goal, an agency must know what assets are in place, their condition, and their expected importance.

The NCHRP scan team report for Project 20-68A[16] summarizes best practices in performance measurement for highway system preservation and maintenance to assist agencies in establishing consistent performance measures for monitoring system preservation and maintenance activities. The scan found that, from a national perspective, one key area of focus in management of transportation system performance is safety, specifically the number of fatalities and serious injuries.

Monitoring the effectiveness of implemented safety strategies also provides important information that can be used to make "course corrections" in safety programs, to document lessons learned, and to establish best practices to guide future safety efforts. Performance measures can provide quantitative information about the relative performance and condition of an asset that can be tracked over time. The integrated safety management process described in *NCHRP Report 501*[17] defines an explicit responsibility for evaluating the effects of safety programs. The *NCHRP Report 500* implementation guides[18] include evaluation criteria for each safety strategy that can be used to design a monitoring program.

As agencies determine and prioritize highway safety needs, they can use transportation asset management techniques and data tools to collect and analyze data, to measure system performance, to identify safety strategies, to set goals, to develop effective performance measures, and to support integrated decisions in programming projects. Although a more robust asset management system supports a wider range of decision-making and analysis capabilities, the process can be scaled to meet an agency's needs and available data resources. The tools and resources discussed in chapters 4 and 5 can assist in quantifying the safety performance of substantive safety features and can assist in safety benefit–cost analysis for 3R and maintenance projects in the same manner as they are for larger-scale operations and capacity expansion projects.

8.4 TOOLS AND RESOURCES FOR INTEGRATING SAFETY INTO SYSTEM PRESERVATION AND MAINTENANCE

As noted in chapters 4 and 5, agencies have at their disposal various analytical tools for use in the planning, programming, engineering, and design stages of project development. Tables 4-3 and 5-2 list the tools most commonly applied for quantitative safety analysis in both stages of project development and the current best practices in analytic tools for substantive safety. The lists are not all-inclusive. New tools continue to be developed as the state of practice in substantive safety evolves.

8.5 REFERENCES

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11. Ibid.

12. American Association of State Highway and Transportation Officials, *Roadside Design Guide*, 4th ed. (Washington, DC: AASHTO, 2011).

13. Road Safe, LLC, RSAP webpage, http://rsap.roadsafellc.com/.

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15. A *safety dike* is a clear zone created on the far side of a T-intersection by relocating utility poles, making the ditch slope traversable, and removing other fixed objects to lessen the severity of a crash if a motorist fails to stop at the intersecting side road.

16. "Best Practices in Performance Measurement for Highway Maintenance and Preservation," Scan Team Report, NCHRP Project 20-68A, Scan 10-03, March 2012.

17. National Cooperative Highway Research Program, *NCHRP Report 501: Integrated Safety Management Process* (Washington, DC: Transportation Research Board, 2003).

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TORT LIABILITY AND RISK MANAGEMENT

9

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9.1 INTRODUCTION

Tort liability is an issue that should be considered throughout the life cycle of transportation facilities. With the integration of safety into that life cycle, explicit recognition of potential tort liability provides an opportunity for effective risk management. Understanding the legal concept of tort liability, together with its defenses and immunities, can ameliorate the circumstances that might otherwise give rise to potential liability. The proactive management of risk involves deliberative decision making through the documentation, the appropriate use of design exceptions, and the continuing evaluation of those decisions.

Safety is a key consideration in those decisions. Although performance-based decision making is becoming an integral part of transportation engineering, some safety and design engineers remain hesitant to fully embrace substantive safety for fear of increasing the risk of tort liability. That reluctance appears to stem from institutionalized views of nominal safety that encourage strict adherence to predetermined design standards. Strict adherence to standards is presumed to pose minimal tort liability risk, and any deviation or flexibility inexorably increases such risk.

That view, however, is incorrect. Professional engineering analysis and design judgment must be used during the life cycle of a transportation facility for effective management of risk, regardless of whether one adheres strictly to standards. Moreover, as the transportation engineering profession progresses from thinking about nominal safety to thinking about substantive safety, it must be understood that the risk of tort liability is a continuum and needs to be assessed as such.

Professional engineering analysis and design judgment during project development are necessary to manage risk, regardless of whether one adheres strictly to standards.

9.2 BACKGROUND AND FUNDAMENTALS OF TORT LIABILITY

9.2.1 Legal Concepts

The following legal concepts related to tort liability are discussed in this section:

- Tort liability
- Public entity liability
- Consulting engineer liability
- Duty: public vs. private
- Negligence
- Mandatory duty
- Dangerous condition of public property
- Discretionary vs. ministerial acts

9.2.1.1 Tort Liability

A tort is a civil wrong arising independently from or outside the obligations of a contract. The commission of a tort does not rise to the level of criminal conduct and is not punished as such. A tort can be an injury to the person or to real or personal property. A person is responsible for his or her tortious conduct and may be answerable in damages to an injured party. Redress for a tort is money damages.

9.2.1.2 Public Entity Liability

Public entities such as cities, counties, and States are generally liable for their tortious conduct. As an arm of the government, those agencies have to assume some obligations, enterprises, and risks, such as emergency services, police protection, and fire protection, that a private entity or business might not choose to take on in a free market. Public agencies are not profit driven but instead are established to provide a public service. As a result, their legal liability usually differs from that of a private entity.

Until 50 years ago, a public entity's liability would have been minimal because of the perception of sovereign immunity—a vestige of the medieval belief in the divine right of kings; that is, "the king can do no wrong." In the 1960s, policy makers and the courts began to rethink the notion that public entities should not be responsible to their citizens for malfeasance. The doctrine began to erode, as supreme courts in many States, one by one, began holding that a public entity ought to be liable to the same extent as a private person. In response to those court decisions and to fears that taxpayers would increasingly bear the costs of large jury verdicts, many State legislatures enacted statutory tort claims acts that limited the circumstances under which public entities could be sued. In some States, they also capped the amount of damages that could be recovered from a public entity. Today, a few States have retained full sovereign immunity; others have waived it entirely. The rest of the States fall somewhere in the middle, retaining some limited level of sovereign immunity but allowing for tort claims to be filed against public entities under certain statutory conditions.

9.2.1.3 Consulting Engineer Liability

Not all engineering services are performed by public entities themselves. Some contract with private engineering firms for such services. Their liability differs from that of public entities. A professional consulting engineer is responsible for his or her tortious conduct. A consulting engineer has a duty to exercise the reasonable care and skill that would be expected of a prudent and ordinarily skilled professional engineer in the same discipline and under similar circumstances. For example, if a consulting engineer fails to exercise care and skill in a project design and if that failure results in injury to a third person, the engineer may be liable for the tort of "negligence" (discussion will follow). For that reason, it is customary for professional consulting engineers to carry professional liability insurance (errors and omissions insurance) to protect against such exposure to liability.

9.2.1.4 Duty: Public vs. Private

The concept of "duty" is fundamental to understanding tort liability. A "public duty" is one owed to the public, not to an individual. Breach of a public duty is generally not actionable. A police officer owes a duty to the public to enforce the law, but if an officer fails to enforce the law (for example, does not cite a driver who is speeding), he or she cannot be held liable for that failure, even if the driver were to crash and cause injury to another.

A "private duty" is one owed to an individual and may be actionable. A person has a duty not to injure another person. If a person intentionally or unintentionally injures someone, that person may have breached a private duty to the other person. The breach of a private duty may give rise to liability to the person injured.

9.2.1.5 Private Duty Created by Common Law: Negligence

Historically, the duty not to injure someone arose out of English common law—a combination of tradition, moral tenets, and legal precedent. Negligence is such a concept. Most torts arise out of negligence and consist of an act or failure to act that breaches a duty of care expected of a reasonably prudent person under the same or similar circumstances. A driver has a duty not to be negligent. If a driver is negligent and causes injury to another, the driver may be liable for that injury. That driver will have failed to perform his or her duty with the standard of care expected of a reasonably prudent driver under the same or similar circumstances. The test is the reasonableness of the act or the failure to act. Negligence is also the basis on which liability may be found against a private consulting engineer who produces a poor design that causes injury to a third party.

Public entities may be subject to liability for common law negligence if their sovereign immunity has been waived. Historically, the waiver may be established by a ruling of the State's highest court or by the State legislature.

9.2.1.6 Private Duty Created by Statute: Mandatory Duty

Some private duties are created by statute. A mandatory duty is one imposed by an enactment (for example, a statute or regulation) that is designed to protect against the risk of a particular kind of injury. A public entity and its employees under a mandatory duty are liable for that particular kind of injury caused by the failure to discharge the mandatory duty. There is no test of reasonableness in that circumstance. Mere failure to discharge the mandatory duty gives rise to liability as a violation of law.

Employees of a public entity, for example, have certain duties associated with their jobs. Those duties can be set forth in statutes or regulations, whereas others may be set forth in policies and manuals. A mandatory duty, imposed by an enactment, is directory in nature and usually evidenced by the use of the word "shall." Examples of those duties can be found in the *Manual on Uniform Traffic Control Devices*,[1] which has been adopted as a regulation in most States. There is no discretion not to perform that duty. A breach of that duty may give rise to liability as a violation of a regulation.

9.2.1.7 Private Duty Created by Statute: Negligence and Dangerous Condition of Public Property

On those occasions when sovereign immunity has not been waived, the State's legislature may establish conditions under which a public entity may be sued. Some States have enacted statutes according to the principles of common law negligence with some exceptions to liability. Other States have created a statutory scheme that provides for the liability of a public entity for a dangerous condition of public property. Those latter statutes were enacted on the basis of the common law private duty relating to premises liability of a landowner to a person injured on his or her property. In States allowing tort claims under those statutory conditions, a public entity can be sued for a dangerous condition of public property; that is, a condition of property that creates a substantial risk of harm to persons using it with due care.

When a public entity has had notice of the dangerous condition and has had sufficient time to remedy or warn of it, yet fails to do so, the agency may be held liable for someone injured as a result of the dangerous condition. That situation can arise from potholes, bad signing or pavement markings, low shoulders, or similar conditions. It can also arise from defective highway design (for example, superelevation, drainage, sight distance, and shoulder width).

9.2.1.8 Discretionary vs. Ministerial Acts

Actions that arise out of private duties can be either "discretionary" or "ministerial." Discretionary acts are those performed by a person vested with the authority to take action on the basis of his or her judgment, not merely to follow a prescribed set of directions. Such actions usually involve high-level policy making. Actions that merely implement those policies or otherwise consist of following directions are considered ministerial (or operational). For example, a decision to select a particular design treatment among a set of options would be discretionary, but the decision to upload the plan sheet to an electronic file would be ministerial. Likewise, a decision to establish a schedule for maintenance activities would be discretionary, but the decision to grade the shoulders on Tuesday instead of Monday would be operational. Whether or not a particular action results from the exercise of discretion or is ministerial in nature has legal ramifications for the defenses and immunities of public entities and its employees.

Although employee duties that are set out in a public entity's policy or "guidance" manuals do not have the force of law, they nevertheless carry considerable legal import. A policy or provision in a manual that uses the word "shall" or is otherwise intended to be required removes any user discretion. In other words, the public entity has determined that the specified action prescribed is so important that there can be no variance. Failure to carry out that act in the prescribed manner violates the standards established by the public entity and, in most cases, will constitute negligence.

Other policies and provisions in a manual that are recommended, as indicated by use of the word "should," may still establish a standard of care for the public entity, its employees, and its private consulting engineers. Deviation from such policies and manual provisions will be tested for the reasonableness of that action under the circumstances. For example, did the act measure up to the standards of a reasonably prudent professional engineer?

9.2.2 Defenses and Immunities

Even in States with limited sovereign immunity, public entities and their employees are still entitled to the same burdens of proof and defenses that a private person would have. Thus, an injured party must prove causation—that an agency's negligence or a dangerous condition actually caused an injury. An agency may assert that the injured party's conduct was the sole cause of the injury, or at least contributed to it. In those cases, the injured party may be completely barred or may be found comparatively at fault, in which case the injured party's recovery would be reduced by the amount of his or her fault.

Most States also provide some affirmative protection to public entities. An important limitation to public entity liability is discretionary immunity (or the "discretionary function exception" under the Federal Tort Claims Act). That immunity provides that

neither a public agency nor public employee is liable for an injury resulting from an act or omission where it was the result of the exercise of the discretion vested in him or her. However, not all decisions are considered sufficiently discretionary in nature to be afforded such protection. The immunity is generally intended to protect high-level policy making.

The basis of immunity is that the law will respect a decision made by an official who is vested with discretionary authority and who has weighed all the alternatives and then exercised his or her discretion in reaching a decision. In fulfilling its mission, an agency is expected to exercise high-level discretion. If an agency being sued for a negligent action that caused an injury can show that the action was the result of a high-level discretionary decision, the agency will be immune from liability.

Many States have a similar but more focused protection commonly called "design immunity." Design immunity, usually codified by statute, provides that neither a public entity nor a public employee is liable for an injury caused by the plan or design for a construction of, or improvement to, public property where the plan or design has been approved in advance by the appropriate body or person exercising discretionary authority, and where there is substantial evidence supporting the reasonableness of the design. Design immunity would also attach where the plan or design conforms to generally accepted engineering or design standards in effect at the time the plan or design was prepared.

The rationale for that rule is the legislature's public policy determination that a design decision made by a professional engineer vested with a discretionary authority, who has weighed the alternatives, should not be second-guessed by a jury of laypeople. However, that immunity is not permanent. Once an agency knows or should have known that a design is no longer reasonable, it has an obligation to remedy or warn of the dangerous condition. It should be noted that those statutory immunities are not available to private consulting engineers. Their conduct is measured against that of a reasonably prudent professional engineer. Their liability is generally determined on the basis of common law negligence (discussed earlier).

9.2.3 Tort Liability Implications of Employing Quantitative Safety

The standards of the engineering profession have been evolving. With publication of the *Highway Safety Manual* (HSM)[2] and the availability of software such as Safety Analyst[3] and the Interactive Highway Safety Design Model,[4] expectations for the engineering profession are being elevated. Sole reliance on nominal safety concepts is becoming outmoded. Raising the bar for engineers pushes the profession toward more emphasis on substantive safety and the use of quantitative analysis tools.

That emphasis can be particularly challenging for smaller agencies such as cities and counties, which may not have the resources or data needed to fully implement the HSM. Those agencies can, nevertheless, effectively manage the risk of tort liability by using the other tools and best practices set out in this report.

The elegance of measuring substantive safety, however, is that it allows the engineer to examine and objectively measure the safety performance of a range of alternative treatments. That process establishes a sound basis for decision making that may significantly reduce the potential for tort liability. However, that conclusion comes with certain provisos:

- The engineer must apply accepted professional practices by using the most appropriate and reliable sources of knowledge. For example, simply obtaining a crash modification factor (CMF) from the CMF Clearinghouse[5] without ensuring that it has sufficient reliability does not meet the standard of care of a professional engineer.
- The engineer must fully understand the analysis and methodology used in measuring quantitative safety performance. Pursuing a certain methodology, without the requisite understanding of the model on which it is based, can lead to aberrant results.
- The engineer's analysis cannot contain errors. Using incomplete data or misapplying a formula undercuts the validity of the conclusion. Results that are counterintuitive are not necessarily incorrect but should be subjected to rigorous verification.
- The engineer should consider the safety implications of alternative treatments beyond immediate crash reduction, such as the future risks arising out of maintenance and operational needs. A particular treatment may achieve a dramatic reduction in the number of crashes at the expense of increased exposure of agency operational and maintenance personnel to traffic risks.
- Finally, the engineer must exercise sound engineering judgment in reaching a decision. The decision must be reasonable after taking into account all the considerations discussed in the previous provisos.

9.3 RISK MANAGEMENT: BEST PRACTICES

The purpose of effective risk management is to avoid or at least minimize potential tort liability in the future. With regard to public agencies, public employees, and private consulting engineers, best practices for risk management fall into four broad categories that all take tort liability into consideration:

- Decision making
- Documentation
- Design exceptions
- Continuing evaluation

9.3.1 Decision Making

Reasonable and rational decision making throughout the life cycle of a transportation facility is the key to good risk management. Although not always the case, a thorough consideration and mitigation of safety throughout that life cycle can also serve as a surrogate mitigation strategy for potential tort liability. Personal injury lawsuits generally arise out of crashes. As stated in the HSM, "A universal objective is to reduce the number and severity of crashes within the limits of available resources, science, technology, and legislatively mandated priorities."[6] Thus, if there are fewer crashes, there will be fewer lawsuits.

A decision-making process that considers alternative treatments can be more important than the selection of a particular treatment itself.

However, traffic safety is not simply about numbers. Sound engineering decision making identifies all relevant factors that affect an engineering decision. Their relative importance must then be weighed in the context of the particular location and facility that is being analyzed with full consideration of alternatives. The decision-making process should also consider the risks associated with ongoing activities after a project has been completed. With regard to safety, that process requires consideration of all relevant elements from a quantitative, substantive, analytical, and technical perspective. Sound engineering judgment must then be used to reach a decision. The process represents an exercise of discretion by a professional engineer and is one that can be defended in a tort lawsuit under discretionary immunity for public agencies and their employees, even if that decision did not result in an alternative that would expect the fewest number of crashes.

The process can also be used to establish that a private consulting engineer was not negligent and met his or her duty to exercise the reasonable care and skill that would be expected of a prudent and ordinarily skilled professional engineer in the same discipline and under similar circumstances. A decision-making process that considers alternative treatments can be more important than the selection of a particular treatment itself. That concept is illustrated by one expert witness who has occasionally been retained by plaintiffs to testify regarding the HSM. His opinion usually focuses on the agency's misuse or misapplication of the HSM or its failure to use the HSM at all, when he can demonstrate that its use would have yielded a better-informed decision than the one reached by the agency. However, he has never offered an opinion that was critical of an agency's choice of a particular treatment from among a number of crash-reducing options that resulted from the proper use and application of the HSM.[7]

9.3.2 Documentation

The legal protections afforded an agency and its engineers rely on reasonableness and on the exercise of discretion. In litigation, a court will require the agency to establish the reasonableness of its decisions and their discretionary nature. To protect the agency, the engineer, and those decisions, the decision-making process to consider alternative safety treatments must be fully documented to record the policy and engineering bases on which those decisions are made.

Without thorough contemporaneous documentation of the decision-making process and all the considerations it comprises, a plaintiff's attorney can make a decision appear to have been made without due consideration or thought. After-the-fact explanations can appear to be rationalizations to cover up a mistake and can be considered not credible. Whether it is a public agency and its employees or a private consulting engineer, success in defending an engineering decision depends on the process that supports it.

As important as documentation is, it is equally important to have a record retention system that allows documentation to be recovered years or decades later, if the need arises. Too often, people make the mistake of discarding or purging important documentation as part of streamlining efforts or to rid themselves of material thought to be compromising.

In that context, it is important to understand the protection afforded by federal law:

> Title 23, United States Code, Section 409 (23 U.S.C. 409):
> **Discovery and admission as evidence of certain reports and surveys**
> *Notwithstanding any other provision of law, reports, surveys, schedules, lists, or data compiled or collected for the purpose of identifying, evaluating, or planning the safety enhancement of potential accident sites, hazardous roadway conditions, or railway-highway crossings, pursuant to sections 130, 144, and 148 of this title or for the purpose of developing any highway safety construction improvement project which may be implemented utilizing Federal-aid highway funds shall not be subject to discovery or admitted into evidence in a Federal or State court proceeding or considered for other purposes in any action for damages arising from any occurrence at a location mentioned or addressed in such reports, surveys, schedules, lists, or data.*[8]

That statute applies to all Federal and State lawsuits arising out of roadway crashes. It protects documents, data, and other material related to Highway Safety Improvement Programs or related to safety improvement projects that may be eligible for Federal funding (whether or not actually funded). Thus, road safety audits, crash records, discussions of alternatives, safety analyses, and similar documentation can be withheld from discovery and excluded from evidence in a personal injury lawsuit.

The rationale behind the law is that self-examination by agencies should be encouraged. To obtain Federal highway funding, agencies must conduct certain safety monitoring of their facilities, thereby establishing a system for implementing safety improvements. Yet the information that must be collected is the very information that would be most useful to a plaintiff bringing a lawsuit against the agency. Congress determined that the good to the public as a whole, fostered by the collection of that material, outweighs the benefit that would provide an advantage to an individual plaintiff by providing the material. The plaintiff must seek the information from other sources.

The statute protects only documents. It does not protect decisions made on the basis of those documents. If the engineer made errors, misapplied certain formulas or tables, or entered the wrong data, and if those errors resulted in a decision that caused injury, the engineer's conduct will be measured against the standard of a reasonably prudent professional engineer under the same or similar circumstances. If the engineer did not meet that standard, that conduct would be considered negligent.

Some documentation related to the project development process may not be protected by 23 U.S.C. 409. In those situations, it is important that documents are well written. Concepts should be clearly stated and not vague or subject to more than one interpretation. They should be factually and objectively stated and not be unsubstantiated opinion.

In selecting a particular treatment, the supporting document should not simply state that it is "more desirable" or "preferable," or that one alternative is "worse" than another. Emotionally charged words and phrases, such as "dangerous," "hazardous," "trap," "black spot," "deficient," "of concern," or "high risk," should be avoided. Those concepts can be objectively and factually described with data without drawing liability-laden conclusions. A "problem" to be solved is a shorthand, lazy conclusion. An "issue" to be resolved invites an objective, fact-driven discussion. Suggesting that something is "required" or "needs to be done" sets up a directive that does not allow for divergent views or engineering judgment.

In short, documentation is needed with an eye toward how it will be perceived by others, such as a judge or jury. Will the documentation assist in supporting a decision, or will it be used as a weapon against it?

9.3.3 Design Exceptions

Design exceptions are a coalescence of the decision-making and documentation concepts described previously. When a particular design feature does not fit neatly within existing policies, standards, warrants, or guidelines because of its context or some other engineering reason, then engineering judgment must be exercised. The design exception process is a means through which that judgment may be exercised. A properly drafted and approved design exception documents the decision-making process, thereby disclosing the discretionary nature of the decision and the engineering judgment exercised. Chapter 5 contains more discussion of the design exception procedure and how it fits into the project development process.

The need for an exception must be documented as part of the design exception process. A typical design exception includes a checklist identifying the issues and considerations that may be relevant to the exception. The checklist may include evaluation and analysis of items such as effects on construction costs, right-of-way, traffic serviceability, safety (number and severity of crashes), traffic operations, future maintenance, community involvement, mitigation costs, and environmental consequences. The process requires consultation with higher levels of decision-making authority, as well as signatory approval by persons charged with the discretionary authority to approve the design exception. Finally, the process has a system for preserving the documents relating to the design exception.

A design exception will stand or fall on the evaluation and analysis part of the process. An important component of the analysis is an assessment of the substantive safety of the design exception. The justification for the exception should be more than cost consideration if there is an adverse effect on safety. Where the number of crashes, severity of crashes, or both appear to increase, mitigation measures can be explored and measured. Alternatives can be considered. The substantive safety implications of the exception can be assessed using quantitative safety performance analytical tools. Those tools, such as those set forth in the HSM, can be effectively used to justify a design exception.

9.3.4 Continuing Evaluation

Fundamental to an agency's management of tort liability risk are programs that identify sites that would benefit from a safety improvement. Effective risk management does not allow an agency to "hide its head in the sand." The agency must use that information to establish priorities for scheduling improvements within the funding constraints that all agencies face.

Good risk management would apply that same practice to completed safety improvements. Having implemented the decisions made during the life cycle of a transportation facility, the agency will benefit by continuing to evaluate those decisions to determine if the expected outcomes were achieved. Quantitative safety performance analyses rely on averages and models. For example, the predictive method in the HSM estimates the expected crash frequency of a network, facility, or individual site. CMFs quantify the change in expected average crash frequency as a result of modifying a site. However, those theoretical values can differ considerably from what actually occurs at the site once the improvement has been completed. Specific outcomes cannot be predicted to 100 percent certainty; therefore, it falls to the agency

to assess the safety effect of improvements in order to determine the relative effectiveness of the treatment.

An agency's monitoring of a site's safety performance after completion of construction provides a sound basis for evaluating the effectiveness of its decisions and better informs future decisions. That evaluation can involve monitoring by both traffic operations and maintenance: Is the facility operating as predicted? Are there unintended or unanticipated outcomes? A good risk management process will have the tools to identify sites where outcomes are not as predicted and can benefit from further improvement. That evaluation may, in turn, trigger the project development process to begin with safety as an integral part and with tort liability and risk management as associated issues to be considered.

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CASE STUDIES

10

Photo courtesy of Thinkstock.

The following case studies illustrate examples of the integration of substantive safety into the various stages of the project's life cycle. Each case study explores in depth a project in which substantive safety has been used in one or more stages of project development. Some of the case studies address the application of substantive safety across all stages; however, most focus on one or two specific areas in project development.

The intent of the case studies is to provide agencies and organizations with examples of how the concept of substantive safety and performance-based safety analysis can be applied to project development and and can be scaled to fit the project context, purpose, and available sources.

MISSOURI'S SMOOTH ROAD INITIATIVE

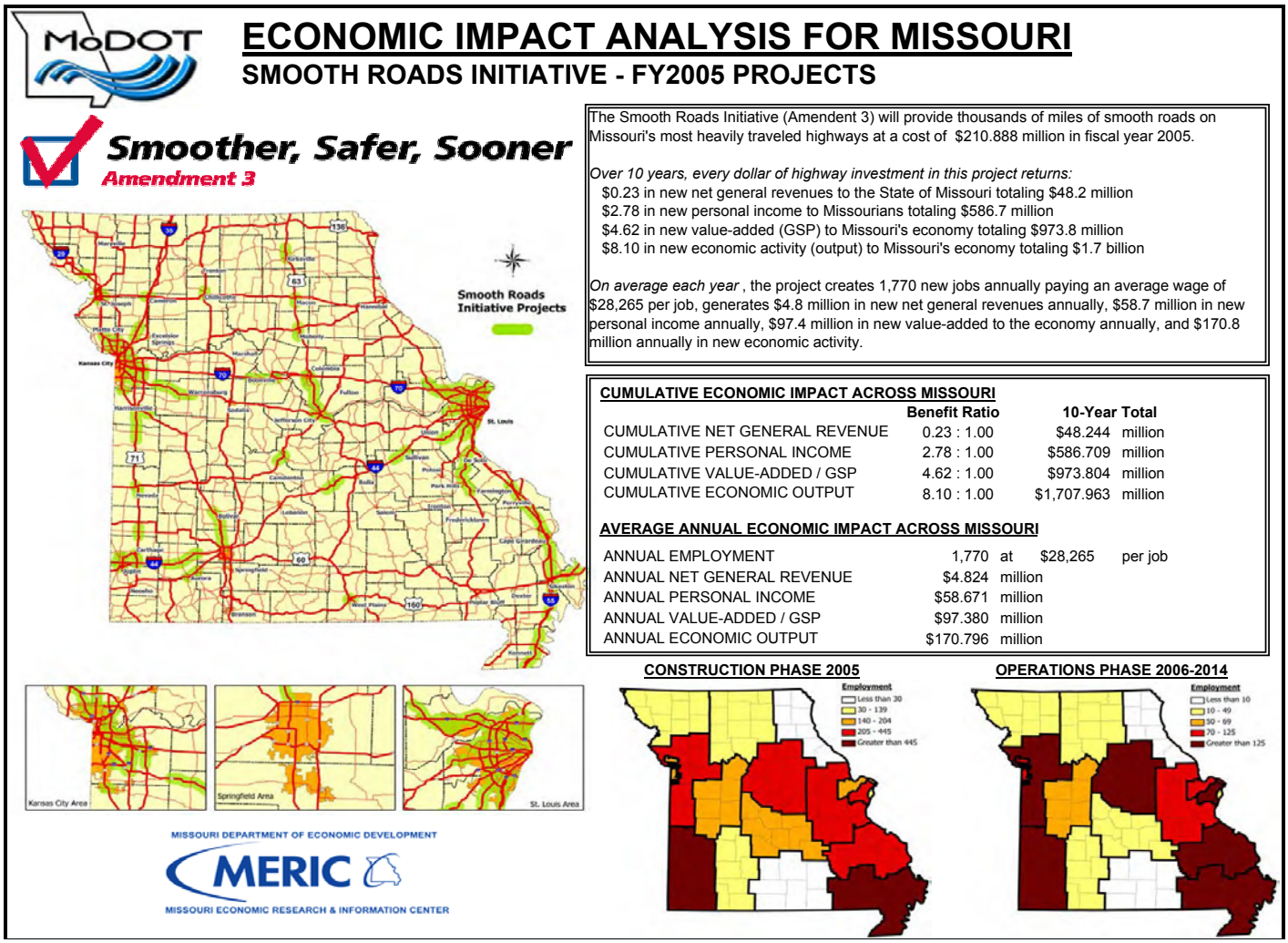
Overview

The Missouri Department of Transportation (MoDOT) developed a method to address safety that is applied during both the planning and maintenance phases of project development. The Diagnosis/Crash Analysis and Countermeasure Development safety analysis tools were used during the safety planning process to diagnose the issue and to develop a safety countermeasure that was implemented through the maintenance program. That effort shows how safety analysis tools can be used to incorporate safety activities into multiple phases in project development.

Project Description

MoDOT began implementing two projects in 2005 to address ride quality along the 5,600 miles of "major roads" (State-system roads functionally classified as principal arterials in the State). The roads represent roughly 17 percent of the 32,000 centerline miles operated and maintained by MoDOT and account for roughly 65 percent of vehicle miles traveled in Missouri. The Smooth Roads Initiative (see figure 10-1) and Better Roads Brighter Future projects incorporated safety improvements along with the pavement improvements. The funding for the $600 million cost was generated through the

Figure 10-1. Economic Impact Analysis for Missouri



Source: Missouri DOT Smooth Roads Initiative.

amendment 3 initiative approved by Missouri voters to improve the pavement on the State's major roads.

Project Purpose and Need

Budgetary constraints in MoDOT's overall capital improvement program led to several years of deferred maintenance on the major roads. Consequently, the 5,600 roadway miles needed repair and repaving to improve ride quality. Crash data show that half the fatalities on the State road system occurred on the major roads. Therefore, MoDOT safety engineers capitalized on the opportunity to add features to the projects that addressed the safety issues associated with those fatalities.

Safety Tools and Best Practices Used

Diagnosis/Crash Analysis. Using the Diagnosis/Crash Analysis tool, MoDOT identified the most common crash types on the major roads. The analysis results showed that lane departure, including cross-median crashes along divided roadways, was the most common crash type.

Countermeasure Development. Using the results of the Diagnosis/Crash Analysis effort, the Countermeasure Development tool identified potential safety countermeasures to address lane-departure crashes. MoDOT used the American Association of State Highway and Transportation Officials' (AASHTO's) *Roadside Design Guide*, the National Cooperative Highway Research Program's *Report 500* series, and experience gained by other State departments of transportation to identify proven, low-cost safety countermeasures for implementation.

Countermeasures were selected because they could be incorporated into the resurfacing projects with minimal additional cost, and because studies have shown that they reduce the frequency and severity of lane-departure crashes. Those countermeasures were road-edge enhancements along roadway segments (wider and brighter edge lines, shoulder rumble strips, edge line rumble strips) and a cable median barrier along the divided roadways. MoDOT selectively replaced signs to improve driver guidance by increasing the font size of the wording. For the Smooth Road Initiative—the first of the two programs

implemented—the addition of those safety features increased the base price for the 2,300–mile project by roughly $67 million.

Evaluating the effectiveness of a safety countermeasure is an important component of the Countermeasure Development tool—determining if the implemented countermeasure contributed to a reduction in the frequency or severity of the subject crash type. The results provide the opportunity to fine-tune elements of a countermeasure or its implementation procedure to improve its effectiveness at other locations. Conversely, evaluation results provide the opportunity to eliminate a countermeasure from further consideration if it is proved ineffective.

MoDOT assessed the performance of the safety countermeasures incorporated into the Smooth Road Initiative through a before–after evaluation that used an Empirical Bayes method. MoDOT structured the evaluation so that each combination of countermeasures was analyzed for each facility type where it was implemented. That level of detail in the analysis allowed MoDOT to understand the degree to which individual countermeasures reduced crashes—or the potential for crashes—on each facility type. The performance measures were crash reduction and benefit–cost ratio (derived with the number of crashes reduced) for all 18 different project types.

Risk Management

Missouri examined 5,600 miles of major roads to improve ride quality. The roads accounted for 65 percent of the vehicle miles traveled but only 17 percent of the State's highway miles. As MoDOT examined those statistics further during project development, it discovered that the selected roads also accounted for roughly 50 percent of fatalities. MoDOT examined a wide range of proven-effective, low-cost safety strategies that could be incorporated into the resurfacing project. Implementation of those strategies resulted in a significant reduction in the number of crashes. The decision to address safety at that stage of project development, for what was otherwise a basic resurfacing project, demonstrated implicit tort liability awareness and resulted in effective risk management.

Results

The project improved ride quality on the major roads, extended the pavement life, and, according to initial estimates, resulted in a 22 percent to 46 percent reduction in severe (fatality and injury) lane-departure crashes, depending on the facility type and safety countermeasure implemented. Of the 18 countermeasure and facility combinations, the following four were reported as being particularly cost-effective:

- Wider markings with resurfacing on rural, multilane undivided highways: benefit–cost ratio = 146
- Wider markings with resurfacing on urban, two-lane highways: benefit–cost ratio = 118
- Wider markings and both centerline and edge line rumble strips with resurfacing on rural, two-lane highways: benefit–cost ratio = 36
- Wider markings without resurfacing on urban, multilane divided highways: benefit–cost ratio = 29

Subsequent Planning Efforts

On the basis of the effectiveness of the implemented safety countermeasures, MoDOT applied the same safety analysis tools during the safety-planning phase of another project development process in 2009. That analysis determined that edge lines should be installed along 650 miles of low-volume rural, two-lane roads. MoDOT used the Countermeasure Development tool to conduct an evaluation of the project.

During the 2 years before the safety countermeasure was implemented, a total of 576 crashes (including 105 with fatalities and injuries) were reported along those roadway segments. During the 2 years after the edge lines were in place, 327 total crashes (including 46 with fatalities and injuries) were reported along the same roadway segments. With regard to safety performance, an Empirical Bayes analysis revealed a 15 percent decrease in crashes after the countermeasure was implemented, including a finding of significance at the 95 percent confidence level. The analysis also found a 19 percent decrease in crashes with fatalities and injuries (not significant at the 90 percent confidence level). The relatively low density of injury crashes prevented the results from being statistically significant despite the 19 percent decrease in total crashes.

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CHICAGO PEDESTRIAN PLAN

Overview

The Chicago Department of Transportation (CDOT) developed a comprehensive pedestrian plan to improve all aspects of the street environment for that transportation mode. The *Chicago Pedestrian Plan* provides an example of using safety analysis tools to incorporate data analysis into planning activities. The Diagnosis Crash Analysis and Network Screening tools were used to provide a data-driven method for use in the pedestrian improvement planning process. The tools were implemented using a geographic information system (GIS)–based platform to organize and analyze the pedestrian crash data. Published reports and study findings were the primary source for the

Countermeasure Development tool used to identify strategies for addressing pedestrian safety issues.

Project Description

An early step in the planning process to address pedestrian safety issues was the collection and analysis of 2005–2009 crash data for pedestrians struck by motor vehicles. The intent of the analysis was to understand when and where those types of crashes occurred and to identify the main contributory factors. The results were combined with stakeholder input from public meetings and guidance from the Mayor's Pedestrian Advisory Council to identify safety mitigation measures and strategies to improve connectivity, livability, and health as presented in the *Chicago Pedestrian Plan*. The pedestrian crash data were incorporated with data from five other data sets to identify high-priority improvement locations. The plan establishes an implementation period and potential funding sources. The plan also suggests that progress toward implementing the strategies and their effectiveness be evaluated regularly.

Project Purpose and Need

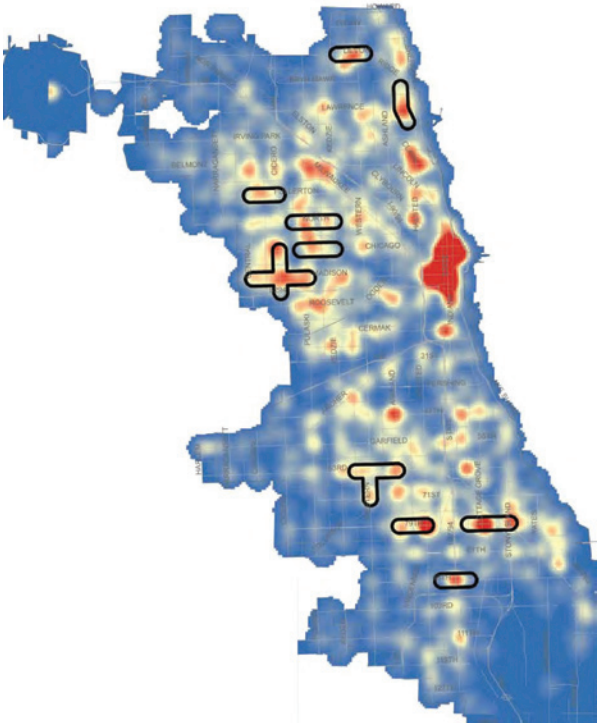
An average of 3,497 pedestrian crashes occurred in Chicago annually between 2005 and 2009, of which 50 crashes (1.5 percent) resulted in a fatality and 15 percent resulted in serious injuries. Although arterial streets account for only 10 percent of the city's street mileage, 50 percent of the fatal and severe injury crashes occurred on them. Hit-and-run pedestrian fatalities occur in Chicago at double the national average (40 percent).

Figure 10-2 highlights (in black) the crash locations identified during the data analysis effort. The locations are corridors of a continuous roadway 1 to 2 miles long that include two or more high-crash intersections. The red areas indicate high concentrations of pedestrian crashes. CDOT developed the plan to improve the pedestrian experience, eliminate pedestrian fatalities in 10 years, and reduce severe injury crashes by 50 percent in 5 years. The plan identifies goals, actions, and milestones to improve the five main aspects of the pedestrian experience: safety, connectivity, livability, equity, and health.

Safety Tools and Best Practices Used

Diagnosis/Crash Analysis. Using the Diagnosis/Crash Analysis tool during the planning process, CDOT identified the predominant crash factors and characteristics. Analysis of the 2005–2009 pedestrian crash data set with a GIS platform provided statistical summaries of when and where pedestrian crashes occurred and of what transportation modes were involved. The analysis included specific crash characteristics, such as pedestrian or driver action, age, and gender; time of day and day of the week; roadway classification and cross section; midblock or intersection location; and lighting and weather conditions. That diagnosis of predominant factors, or characteristics that appear more frequently in the data, allowed CDOT to focus on developing improvement strategies that would have the greatest potential to reduce the frequency and severity of pedestrian crashes.

Figure 10-2. Fatal and Serious Injury Pedestrian Crash Density and High-Crash Corridors



Source: Chicago Department of Transportation, City of Chicago 2011 Pedestrian Crash Analysis, *Map 7.*

Network Screening. The Network Screening tool was applied on a GIS platform that included the citywide data sets listed in table 10-1 to identify high-priority locations for pedestrian improvements. The different data sets were weighted using the

Table 10-1. Selected Categories and Respective Data Sets

Categories	Data Set
Safety	Pedestrian crash data, street functional classification, traffic signal control, crime data, proximity to schools/parks/libraries, hospitals, and community centers
Connectivity	311 call data about sidewalk conditions and snow removal, as well as proximity to barriers on Interstates and expressways
Livability	Distance to train stations and bus stops, priority bus routes, proximity to land uses B and C, employment density, and proximity to universities/colleges
Health	Hospitalization rate of diabetes and hypertension, heart disease mortality rate, asthma rate, and heat island coverage
Equity	Areas of low income, percentage of population with a disability, percentage who walk/bike/transit to work, population density, and automobile ownership rates

Table 10-2. Chicago Pedestrian Plan: Strategies for Safer Streets

• Marked crosswalks	• Road diets
• In-road "State Law Stop for Pedestrians" signs	• Speed feedback signs
• Pedestrian refuge islands	• Roundabouts
• Traffic signals and beacons	• Chicanes
• Accessible pedestrian signals	• Traffic calming
• Pedestrian countdown timers	• Skinny streets
• Leading pedestrian intervals	• Bump-outs
• Lagging left turns	• Neighborhood traffic circles

results of a survey that asked participants to rank a list of potential factors by importance and to suggest other factors that should be included in the process to define the pedestrian experience. Pedestrian crash data were one of the many factors included in the GIS model to simulate the five areas of the pedestrian experience.

The GIS model allowed CDOT to screen all locations within the city's roadway network and to highlight those locations with the most serious pedestrian issues (figure 10-3). High-priority areas were defined as locations in the top 25th percentile of the network screening results. CDOT and stakeholders used those results in the project selection process. The decision-making process and project implementation depend on many considerations, including project-specific needs, funding, and community support.

Comparing figure 10-1 with figure 10-3 indicates that the high-priority locations identified with the Network Screening tool using the five components of the pedestrian experience do not include some locations identified in the diagnosis and crash analysis as having high pedestrian crash frequencies. That finding supports the notion that safety is just one of several considerations for improving the pedestrian experience in Chicago.

Countermeasure Development. The Countermeasure Development tool identified strategies that could be implemented to address safety issues and to improve the pedestrian experience. The safety countermeasures, or strategies, were selected for inclusion on the basis of published documentation that indicates a particular strategy has been proved effective at reducing pedestrian crashes. The strategies can address issues for a variety of roadway classifications and intersection control types.

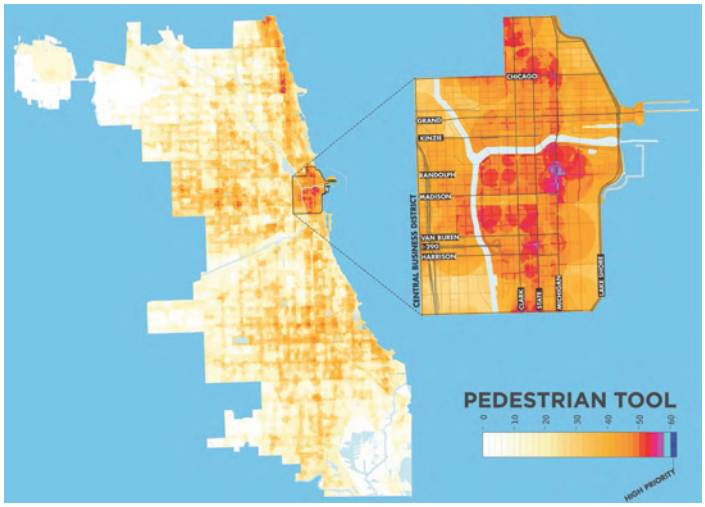
In addition to the strategies listed in table 10-2, the plan includes enforcement and educational strategies selected from the latest research and documentation of national best practices. The Countermeasure Development tool gives CDOT a reference to use when selecting safety improvements to address specific issues at a particular location. See the *Chicago Pedestrian Plan* website (http://chicagopedestrianplan.org) for more information.

Conclusions

The *Chicago Pedestrian Plan* was developed within a systemic context: diagnostics for the whole roadway network were performed, and an array of proven safety strategies to address the findings was developed. To further improve the pedestrian experience in Chicago, the Diagnostic/Crash Analysis tool could be used to perform a detailed analysis of the individual locations within the top 25th percentile. The results of those analyses would help identify strategies that could address the needs of a particular location. At that detailed level of analysis, a substantive safety approach can be incorporated by considering the crash modification factors (CMFs) associated with those strategies to determine the one with the most potential for reducing the frequency and severity of pedestrian crashes at a particular location. That effort would inform the next step in the process to program the design and implementation of specific improvements.

Another step to incorporate substantive safety analyses into the pedestrian improvement program would be to develop guidelines and processes for the evaluation efforts that are committed to in the pedestrian plan. The guidance could include time periods, data to be collected, methodology, and dissemination of results. The results can inform ongoing planning efforts by providing feedback about the effectiveness of a safety strategy and its viability for

Figure 10-3. GIS Model Output of High-Priority Pedestrian Areas



Source: Chicago Department of Transportation, Chicago Pedestrian Plan, *2012.*

continued implementation at other locations. The tools available can be updated with that information, thereby removing ineffective strategies from further consideration. Data collected as part of the evaluation effort could be used to develop local CMFs that would improve the accuracy of the planning efforts to select safety strategies and to estimate their crash reduction potential. Evaluation efforts could also provide more accurate implementation costs to incorporate into ongoing programming efforts.

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WASHINGTON STATE TRANSPORTATION IMPROVEMENT BOARD SAFETY ANALYSIS TOOL

Overview

The Washington State Transportation Improvement Board (TIB) recognized the need to update the safety criteria used during the application evaluation process for transportation funding requests. TIB used the concepts and techniques that are the premise of the Safety Analysis with Predictive Models safety analysis tool to develop evaluation criteria and a tool that assists with the preparation and evaluation of project funding applications built on those criteria. This case study provides an illustration of incorporating substantive safety into the planning and programming phase of project development.

Background and Project Description

TIB is an agency that provides funding for transportation projects throughout Washington State that best address the criteria established by TIB. Each year, local jurisdictions submit an application to request funding for projects under a particular category, one of which is safety. In the past, all the categories were considered together and ranked according to a cumulative score. That approach caused some inconsistencies in the selected projects and an underrepresentation of projects in some of the categories. Therefore, TIB elected to separate the categories and to evaluate them individually. That decision provided a framework within which the evaluation effort could uniformly follow a more data-driven and performance-based approach that would result in the selection of projects within each category and more equitable funding allocations.

TIB modified its processes to incorporate a more performance-oriented approach for all of its funding categories. TIB is an independent State agency that distributes and manages street construction and maintenance grants for 320 cities and counties throughout Washington State. Agency programs are driven by performance feedback and lean process improvements. Under the Urban Arterial Program, cities with populations greater than 5,000 and counties with urban unincorporated areas submit grant applications for arterial projects. In the past, projects scoring well needed to meet a combination of factors, such as poor street condition and safety issues. The effect of averaging scores sometimes meant that the top projects in a single area, such as safety or growth and development, were not selected.

In 2013, Urban Arterial Program criteria were redeveloped to make a stronger connection to statewide transportation priorities. Under the new criteria, TIB scores and then ranks applications in the following four areas, called "bands":

1. Safety
2. Growth and development
3. Physical condition
4. Mobility

Additionally, all projects are rated on sustainability and constructability.

The decision to update the selection process and the criteria provided a framework within which the evaluation effort could uniformly follow a more data-driven and performance-based approach.

This case study focuses solely on the safety category. With the intent to determine which projects had the highest potential to improve safety performance, TIB historically used a combination of crash rates, roadway characteristics, and traffic volumes to score projects submitted in the safety category. Some of the criteria relative to roadway characteristics included absence of sidewalks, inadequate drainage, vertical and horizontal alignment issues, and parking. Each criterion had a point value assigned, and they were summed to obtain a project score. Crash history had an associated point value that contributed to the score as well.

Although the criteria included in the applications may relate to or have an effect on the safety performance of a location, they did not always provide a complete picture of the existing safety issues or those that would be addressed by the project. Projects that scored well in crash history sometimes did not fare well when all safety criteria were considered. To identify safety projects that would provide the maximum return on investment, TIB initiated an effort to revise its safety evaluation methodology to be more specific and performance based while being sensitive to the capabilities of the local agency stakeholders who prepare and submit the applications. Once the new criteria were established, the project produced an analysis tool that used the principles and procedures of the predictive methodologies outlined in AASHTO's *Highway Safety Manual* (HSM). Begun in 2011, the revised evaluation criteria were recommended, and the tool was completed in May 2012.

Figure 10-4. Sample TIB Safety Analysis Tool Output

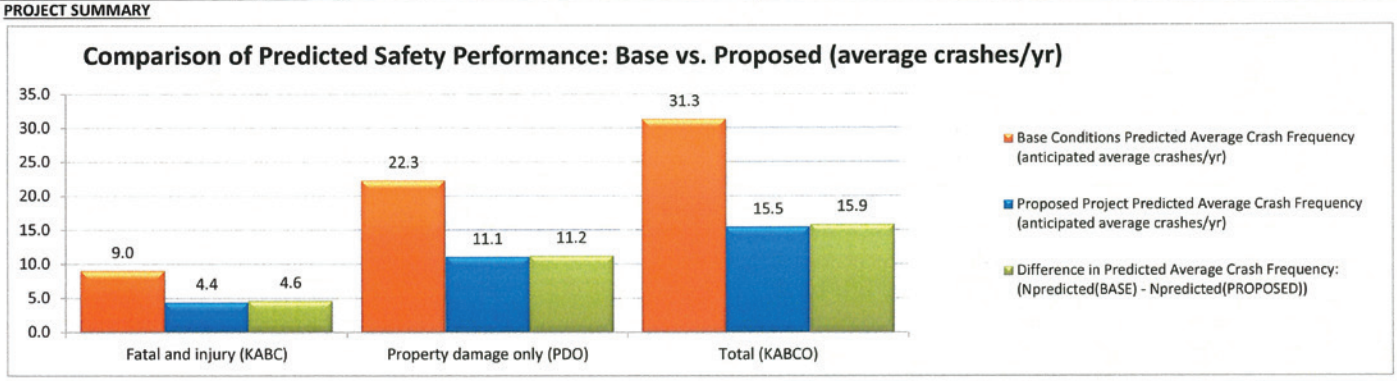
PROJECT SAFETY PERFORMANCE COMPARISON SUMMARY REPORT

Predicted Crash Frequency Reduction	Total Crashes	15.9	Injury Crashes Only	4.6

General Information

Project Name	NE 85th Street	Legislative District(s)	48
Project Description	0	Congressional District(s)	1
Reference Number	0	Agency Contact	-
Agency	Kirkland	Phone Number	-
Arterial Name	NE 85th Street	Email Address	-
Functional Class	Urban Principal	Analysis Year	2015
Project Limits	120th Ave NE to 132nd Avenue NE	Analyst	-
Region	Puget Sound Region	Date Performed	9/13/2013

PROJECT SUMMARY



Project Element	Total Crashes/yr (KABCO)			Fatal and Injury Crashes/yr (KABC)			Property Damage Only Crashes/yr (PDO)		
	Base predicted average crash frequency $N_{predicted\ (BASE)}$	Proposed predicted average crash frequency $N_{predicted(PROPOSED)}$	Difference (Base-Proposed)	Base predicted average crash frequency $N_{predicted\ (BASE)}$	Proposed predicted average crash frequency $N_{predicted(PROPOSED)}$	Difference (Base-Proposed)	Base predicted average crash frequency $N_{predicted\ (BASE)}$	Proposed predicted average crash frequency $N_{predicted(PROPOSED)}$	Difference (Base-Proposed)
INDIVIDUAL SEGMENTS									
Segment 1	4.8	1.6	3.1	1.2	0.3	0.9	3.5	1.3	2.2
Segment 2	16.0	4.8	11.1	4.2	1.0	3.2	11.8	3.8	8.0
Segment 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Segment 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Segment 5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Segment 6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Segment 7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Segment Total	20.7	6.4	14.3	5.4	1.3	4.1	15.3	5.1	10.2

Source: Washington State TIB Funding Application, Safety Analysis Tool, Washington State Transporation Improvement Board.

Project Purpose and Need

The purpose of the project was to revise the application process and evaluation methodology to improve the quality of the projects that TIB selected for funding. The revisions had to produce processes and methodologies consistent with the current state of practice. The application process needed to be simple enough to be understood by all potential agency personnel who would prepare and submit applications, yet sophisticated enough to adequately assess the expected safety performance of a proposed project.

Safety Analysis Tools and Best Practices Used

Recent advancements in the safety planning industry and knowledge base provided the opportunity to incorporate state-of-the-practice substantive safety analysis methodologies into the TIB application and evaluation process for safety projects. To facilitate that endeavor, TIB developed an analysis tool that used the principles of the HSM predictive method.

In addition to the data inputs used in the substantive analysis, the application includes the opportunity to select common countermeasures proposed for incorporation into the safety project. Using that information, the safety evaluation tool determines the predicted and expected annual crash frequency. When the expected crash frequency exceeds the predicted crash frequency, that difference becomes the potential for safety improvement (PSI). The PSI for a fatal and injury crash is determined separately from the PSI for a property damage crash. Adding the two PSI values provides a total crash PSI assessment for the project.

Figure 10-4 shows a sample output from the TIB analysis tool that summarizes the predicted annual crash frequency for both existing (orange bar) and proposed (blue bar) conditions for a project. When the project is predicted to reduce the

annual crash frequency, the green bar displays the magnitude of crash reduction.

Because of the diversity of TIB's customers (ranging from professional planning and engineering experience, to no related experience, to anywhere in between), the complex HSM inputs and methodologies may have been too challenging and discouraging for the personnel in many of the jurisdictions, particularly smaller agencies, which typically apply for funding. Thus, the tool was developed using the principles of the HSM, but it was simplified where possible to achieve a broader sense of understanding for users of all experience levels. That simplification resulted in (a) the exclusion of some input information that could be cumbersome to collect or confusing and that did not have a significant effect on the analysis results, (b) the alteration of how some information requests were worded, and (c) the provision of ranges for certain inputs to simplify the data collection effort.

Customers do not actually use the analysis capabilities of the tool directly; rather, they enter the requested data on the application that serves as the input for the analysis methodologies. TIB district engineers transfer the information submitted on the applications into the tool for analysis and scoring. The high volume of applications received mandated that the tool be simple and easy to understand, like the inputs on the application.

The amount of information requested on the revised applications is not significantly more than what was previously required, but the types of information requested have changed to better identify whether a safety issue exists and whether the proposed project addresses it. The tool includes methodology from additional research that aims to address other potential project features that are common among the applications that may influence safety but that are not in the current edition of the HSM. For each project, the tool provides output regarding (a) the potential for safety improvement of the existing site, (b) the difference between the base and proposed predicted model crashes, and (c) the difference between the base and proposed expected crashes.

Conclusion

By developing the safety evaluation tool on the basis of substantive safety in addition to other qualitative criteria, TIB is now able to quantify the expected safety performance of each project, compare and prioritize projects according to those parameters, and promote consistency in the evaluation process. That framework provides a data-driven process for selecting those projects with the highest potential to enhance traffic safety in the local communities served by TIB.

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SR 264 TRAFFIC SAFETY EVALUATION, NAVAJO COUNTY, ARIZONA

Overview

As part of alternatives development during the design phase for the State Route (SR) 264 project, the Arizona Department of Transportation (ADOT) evaluated the potential effects of various safety improvements. The Diagnosis/Crash Analysis, Countermeasure Development, Alternative Analysis with Predictive Models, and Economic Analysis safety analysis tools were used to diagnose the safety issues and to identify countermeasures to include in the final design. This project provides an example of how to use safety analysis tools to identify solutions that address safety needs cost-effectively.

Background and Project Description

SR 264 is an undivided, two-lane rural minor arterial that runs east and west. The project area is a 24.6-mile section of SR 264 between Burnside Junction and Summit Road in Navajo County (see figure 10-5). The typical cross section was 12-foot travel lanes and zero- to 1-foot shoulders with intermittent right- and left- turn and passing lanes. Traffic volume ranged from 4,100 to 6,400 vehicles per day in 2010; on the basis of the 2036 forecasts, future volumes are expected to range from 5,400 to 12,150 vehicles per day.

An analysis was conducted using projected traffic volumes for the period from 2016 to 2036 to determine the effect on highway safety for three improvement alternatives: (a) widening the shoulders to 5 feet, (b) widening the shoulders to 8 feet, and (c) superelevation improvements using current guidance from AASHTO. All three alternatives (alternative A, alternative B, and superelevation) maintained 12-foot travel lanes and included shoulder rumble strips, centerline pavement markings, flatter slopes, guardrail installation, extended drainage structures, delineation, and recessed pavement markers. The design phase was completed in March 2013, and construction was completed later that year.

Project Purpose and Need

The goal of the SR 264 project was to improve safety and to reduce the number of fatalities and severe injuries. For the period 2007–2010, 56 crashes occurred: 6 fatal crashes, 28 injury crashes, and 22 property damage-only crashes.

Safety Tools and Best Practices Used

Diagnosis/Crash Analysis. This safety analysis technique was applied during the alternatives development process to identify the most common crash types in the project area. The results showed that nearly half of the crashes involved a single vehicle running off the road during the 4-year analysis period. Those findings informed the application of the Countermeasure Development safety analysis tool.

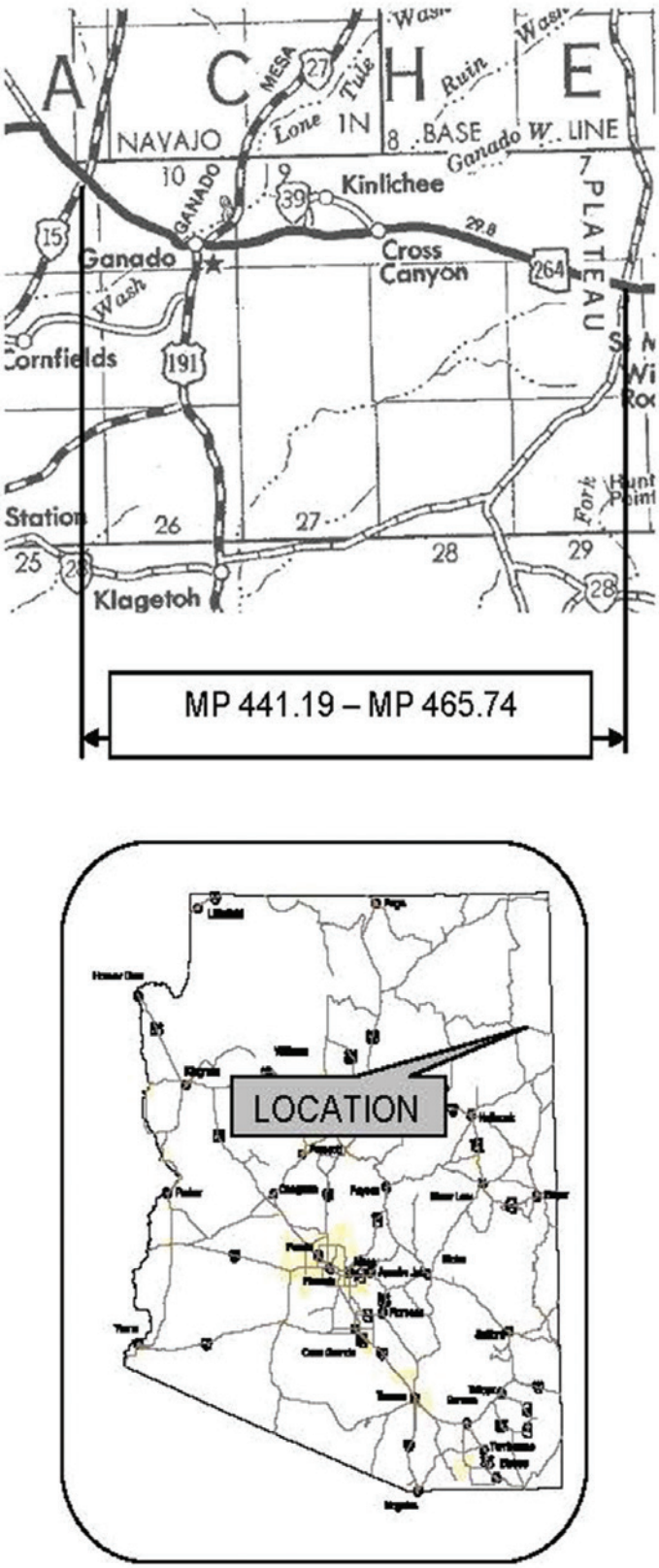
Countermeasure Development. This analysis technique was used to identify potential countermeasures that address the predominant run-off-the-road crash type. At the onset of the application of this tool, ADOT chose to implement proven, low-cost safety countermeasures and used a national resource—AASHTO's *Highway Safety Manual*—to identify them. The potential countermeasures were selected for analysis with a predictive model, because studies have shown that they reduce the frequency and severity of run-off-the-road crashes.

Alternative Analysis with Predictive Models. The safety analysis was applied using the Federal Highway Administration's (FHWA's) Interactive Highway Safety Design Model (IHSDM) crash prediction module. That module of the IHSDM safety analysis tool, which implements the HSM predictive methods, was used to predict the percentage of crash reduction that could be achieved with each of the three countermeasures. Predictive analyses were conducted to estimate the number of crashes by severity for the no-build and the safety improvement conditions.

The analysis used ADOT's locally derived crash severity distributions, which were developed using crash data from roadways with similar characteristics within Navajo Nation and Hopi tribal lands. Because ADOT had not yet developed calibration factors for the HSM models, the IHSDM analysis used the default HSM calibration factors. Such factors account for the unique aspects of crash databases, reporting levels, demographics, terrain, and climate associated with each State. Given that the analysis was comparative and that both crash reduction and benefit–cost relationships were developed and compared with the no-build condition for each alternative, the lack of ADOT calibration factors did not affect the analysis' conclusions. Even without calibration factors, the IHSDM and other HSM-based quantitative safety analyses can be used for comparative alternatives analysis during project development

Table 10-3 shows that alternatives A and B are expected to perform better than the no-build base condition from a substantive safety perspective. The effect of providing superelevation rates that comply with current design standards corresponds to an expected 0.2 percent reduction in total, severe, and property damage crashes over the 20-year analysis period. Shoulder widening could produce a greater effect on safety and reduce crashes even more. The 8-foot shoulder proposed with

Figure 10-5. SR 264 Project Area



Source: Arizona Department of Transportation, Traffic Safety Evaluation Report.

Table 10-3. Expected Crash Frequency by Severity: 2016–2036

Alternative	Total Crashes	Fatality and Injury Crashes	Property Damage Only Crashes	Reduction in Total Crashes over Existing Conditions	Percentage Reduction
No build	636.4	283.4	353.0	–	–
Alternative A	531.6	230.5	301.1	104.8	16.5
Alternative B	504.2	216.8	287.4	132.2	20.8
Only superelevation improvements	635.3	282.7	352.6	1.1	0.2

Source: Arizona Department of Transportation, "Traffic Safety Evaluation Report."

alternative B could potentially reduce about 4 percent more crashes than the narrower shoulder proposed with alternative A.

Economic Analysis

The Predictive Model safety analysis tool indicated that both shoulder-widening alternatives could reduce crashes compared with the no-build condition. Because both would accomplish the goal of reducing crashes, ADOT also applied the Economic Analysis safety analysis tool to further aid in the decision-making process. A benefit–cost analysis was performed to determine which alternative would provide a greater return on investment. The benefits of each alternative were calculated by converting the reduced number of crashes into a dollar value that represented societal cost. The societal crash cost for each type of crash severity was consistent with those typically used by ADOT and FHWA's Arizona division. The benefit–cost ratios (table 10-4) for alternatives A and B and the superelevation improvements alternative indicate that only alternatives A and B would be beneficial from an economic perspective. However, of the three, alternative A would provide the greatest return on investment.

Table 10-4. Benefit–Cost Ratio: Design Alternatives

Alternative	Annual Benefit	Annual Cost	Benefit–Cost Ratio
Alternative A	$3,873,681	$1,680,561	2.30
Alternative B	$5,084,207	$2,678,713	1.90
Superelevation improvements	$41,807	$135,464	0.31

Source: Arizona Department of Transportation, "Traffic Safety Evaluation Report."

Preferred Alternative

The preferred alternative was selected after considering the results produced by the application of the safety analysis tools. Alternative B, the 8-foot shoulder widening, could provide the greater reduction in crashes. However, alternative A, 5-foot shoulder widening, would provide the greater safety return on investment (more lives and injuries saved per dollar invested) and, therefore, was selected as the preferred alternative to incorporate into the design.

Risk Management

ADOT studied a 24.6-mile section of Arizona SR 264 with the goal of reducing the number and severity of crashes. Using the IHSDM to implement the predictive method set out in the HSM, ADOT examined various alternative treatments. Alternative A predicted a 16.5 percent reduction in crashes; alternative B, a 20.8 percent reduction. Although a greater reduction in crashes was predicted for alternative B, alternative A's benefit–cost ratio was significantly more favorable. ADOT chose alternative A. That choice is an example of where selecting an alternative with a substantial reduction in crashes but not the greatest reduction is an exercise of sound engineering judgment. It is a discretionary decision that is not expected to give rise to tort liability.

Conclusions

Quantitative safety analyses were conducted to evaluate the predicted safety performance (crashes and their severity) of various design alternatives. Consulting national resources resulted in the identification of countermeasures that are proved to be effective at reducing the predominant crash type. Application of the safety analysis tools and results allowed ADOT to select the most cost-effective improvement that would meet the safety need for SR 264.

To maintain a focus on substantive safety in Arizona, ADOT could conduct before–after evaluations to assess the effectiveness of the shoulder widening that was incorporated into the project design. The results of that evaluation could inform future planning and programming efforts for safety improvements along SR 264 and similar highways in the State.

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LOUISIANA INTERSTATE 12 TO BUSH

Overview

The Louisiana Department of Transportation and Development (LADOTD) proposed the construction of a four-lane highway between I-12 and SR 21 in Bush, Louisiana, to relieve congestion on the highways. LADOTD used the Alternative Analysis with Predictive Models safety analysis tool to compare the proposed alternatives with the no-build alternative. This case study provides an example of how using safety analysis tools can contribute to the selection of the appropriate alternative during the environmental and alternatives analysis stage of engineering and the design phase of a project.

Project Description

The project area is located in St. Tammany Parish and encompasses 245 square miles, including the cities of Abita Springs and Pearl River and parts of Slidell and Covington. The U.S. Army Corps of Engineers, in coordination with LADOTD, initiated a study to define and assess potential alternatives for the Environmental Impact Statement (EIS). The alternative alignments between Bush and I-12 were 17.4 to 21.0 miles long (figure 10-6).

Phase I, a preliminary corridor study that documented existing conditions and established the purpose and need, was completed in 2002. Phase II, the alignment study, was completed in 2004. Phase III, completed in 2008, developed and evaluated the alternatives to determine their environmental impacts. The draft EIS was submitted in 2009 and finalized in 2012. The Record of Decision was published in June 2012. Three firms were contracted in July 2013 to provide engineering services. The preconstruction engineering services, including survey, preliminary roadway and bridge design, among others, started in 2013.

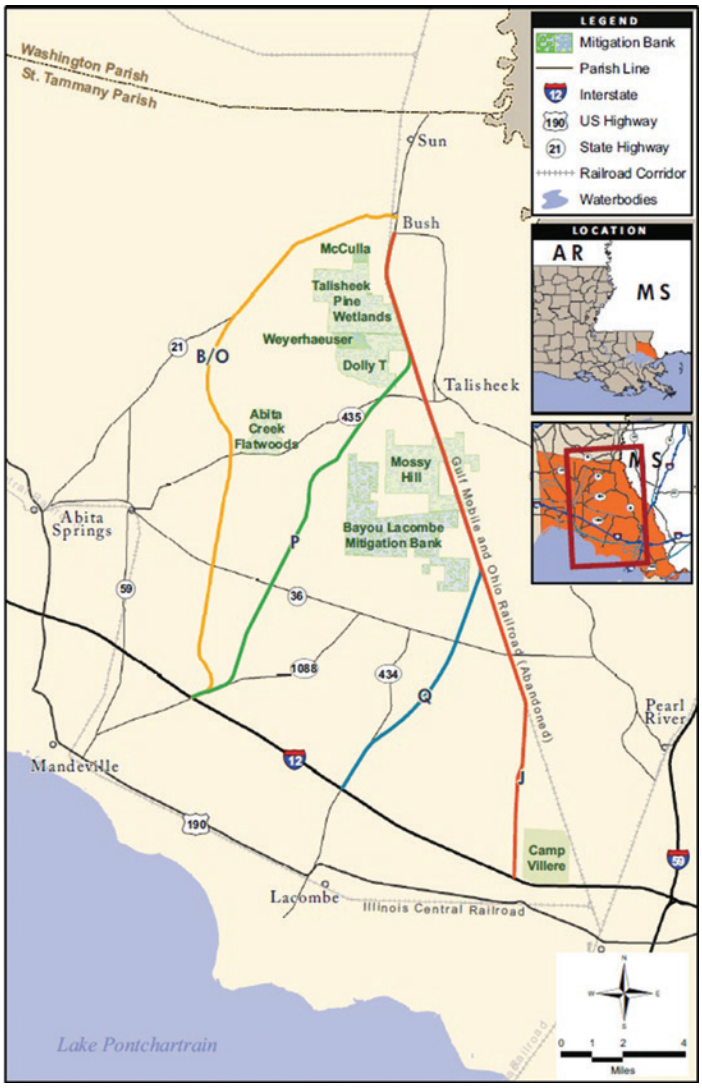
Project Purpose and Need

The purpose of the project is to construct a high-speed, four-lane, rural arterial highway that is between I-12 and SR 21 and that will address regional transportation mobility needs and potentially stimulate economic growth and activity in Washington and St. Tammany Parishes. In addition to alleviating congestion, reducing travel time, and reducing the potential for crashes, the highway had to be constructed to comply with a State legislative mandate (Louisiana Revised Statute 47:820.2.B[e]).

Safety Tools and Best Practices Used

LADOTD applied the Alternative Analysis with Predictive Models safety analysis tool using FHWA's IHSDM crash prediction module. The module, which implements the HSM predictive methods, was used to predict the number of crashes for each alternative in design year 2035. That safety analysis was conducted to quantify the safety performance of each alternative

Figure 10-6. Project Study Area and Final Alternatives



Source: I-12 to Bush EIS, Louisiana Department of Transportation.

with regard to the predicted number of crashes by severity and their associated societal costs over the life of the project. The build alternative's divided roadway with controlled access was expected to provide greater safety benefits than does the existing two-lane undivided highways with numerous access points. The IHSDM analysis was used to quantify safety performance and estimated expected crashes by alternative. That information was used as one of several evaluation criteria to evaluate the no-build and final four alternatives as part of the detailed impact analysis for the alternatives and selection of a preferred alternative.

At the time the safety analysis was conducted, LADOTD had yet to determine State-specific calibration factors for the predictive method. Such factors account for unique aspects of crash databases, reporting levels, demographics, terrain, and climate associated with each State. Therefore, HSM default values were used for the analysis. Using the no-build alternative as a benchmark, the resultant numbers of crashes predicted by the IHSDM were used for relative comparisons between the alternatives. The project

Table 10-5. Alternatives Safety Analysis Summary: 2035

Rank	Alternative	Total Crashes	Crashes Reduced	Total Cost of Crashes	Potential Reduction
1	P	820.8	87.3	$22,060,778	$2,345,187
2	J	828.2	79.9	$22,257,509	$2,148,456
3	Q	851.6	56.5	$22,887,479	$1,518,486
4	B/O	902.9	5.2	$24,278,285	$138,680
5	No build	908.1	0	$24,405,965	0

team disaggregated the predicted crashes into severity levels and converted them into a dollar value using cost data from the National Highway Traffic Safety Administration's 2000 technical report, *The Economic Impact of Motor Vehicle Crashes*, and updated them with the Consumer Price Index.

Table 10-5 shows the predictive safety performance results reported in the final EIS. The safety performance evaluation for 2035 indicated that all alternatives predict reductions in crashes compared with the no-build alternative. The "Potential Reduction" column presents the monetary difference between each alternative and the no-build option realized by the potential reduction in crashes.

All four alignments were designed using the same criteria (such as design speed and cross-sectional elements), but their unique characteristics had meaningful differences in their predicted safety performance (crashes reduced). Ranked highest in safety performance, alternative P is predicted to result in roughly 10 percent fewer crashes than the no-build alternative, resulting in a projected $2.3 million cost savings to society.

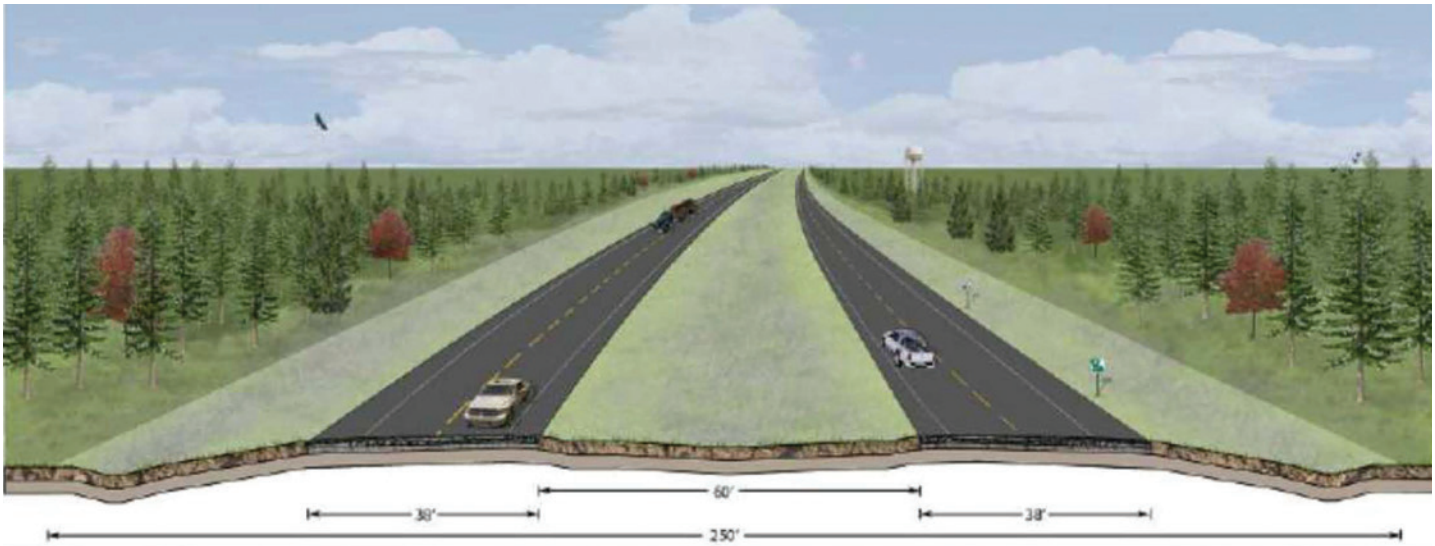
Additional information about LADOTD highway safety methods and tools can be found on LADOTD's website (http://www.dotd.la.gov/planning/highway_safety).

Preferred Alternative

The Corps of Engineers issued the Record of Decision in June 2012 for alternative Q (see figure 10-7), which was determined to be the most environmentally acceptable alternative that would achieve the project purpose and need. The preferred alternative was selected after assessing the costs and benefits; impacts of the full range of environmental, socioeconomic, cultural, and transportation performance considerations; and consideration of public and agency comments developed as part of the draft and final EIS processes. Safety was considered as part of the traffic and transportation impacts when assessing the potential physical, natural, and social environmental consequences of each alternative.

Alternative Q does not have the highest predicted safety performance, but it is still expected to experience fewer crashes and to result in less societal cost expended than the no-build alternative. Even more important, quantitative safety analysis was used as part of the alternatives analysis, allowing safety performance to be a point of comparison and information in selection of a preferred alternative.

Figure 10-7. Graphic of Preferred Alternative



Source: I-12 to Bush EIS, Louisiana Department of Transportation.

Conclusions

Agencies responsible for executing the requirements of the National Environmental Policy Act and for selecting the preferred alternative make such decisions by balancing many effects and by trading off relative values. An agency is not compelled to select the alternative believed to be the "safest" (in the context here, alternative P, which predicts the greatest safety benefit), just as it is not compelled to select the lowest-cost alternative or the alternative that has the least impact on a particular environmental asset, such as wetlands.

This project is a good example of how the new knowledge base on substantive safety can be applied to the environmental process and alternative analysis. It presents an interesting snapshot of how agencies are transitioning from the nominal safety approach to using substantive safety, or actual quantified safety performance, in making project decisions. In this case, it was assumed that traffic diverted from existing roadways with lesser design standards to one of the proposed alternative alignments with higher design standards would result in a reduction in traffic crashes. That assertion follows the more traditional belief that to design to standards begets safety.

Although the assumption was correct in that the alternatives—which all included a raised median with limited access points—decrease the number of conflict points and thereby improved safety, it did not take into consideration the other safety implications of each design configuration, nor did it provide differentiation between alternatives. The application of substantive safety analysis by alternative allowed safety to become a differentiating feature in the evaluation of alternatives and selection of the preferred alternative.

This project is an example of where selecting an alternative with a substantial reduction in crashes but not the greatest reduction is an exercise of sound engineering judgment. Although the selected alternative was not the alternative with "best" safety performance, the more important aspect was that the selection of an alternative was made considering all impacts, including safety.

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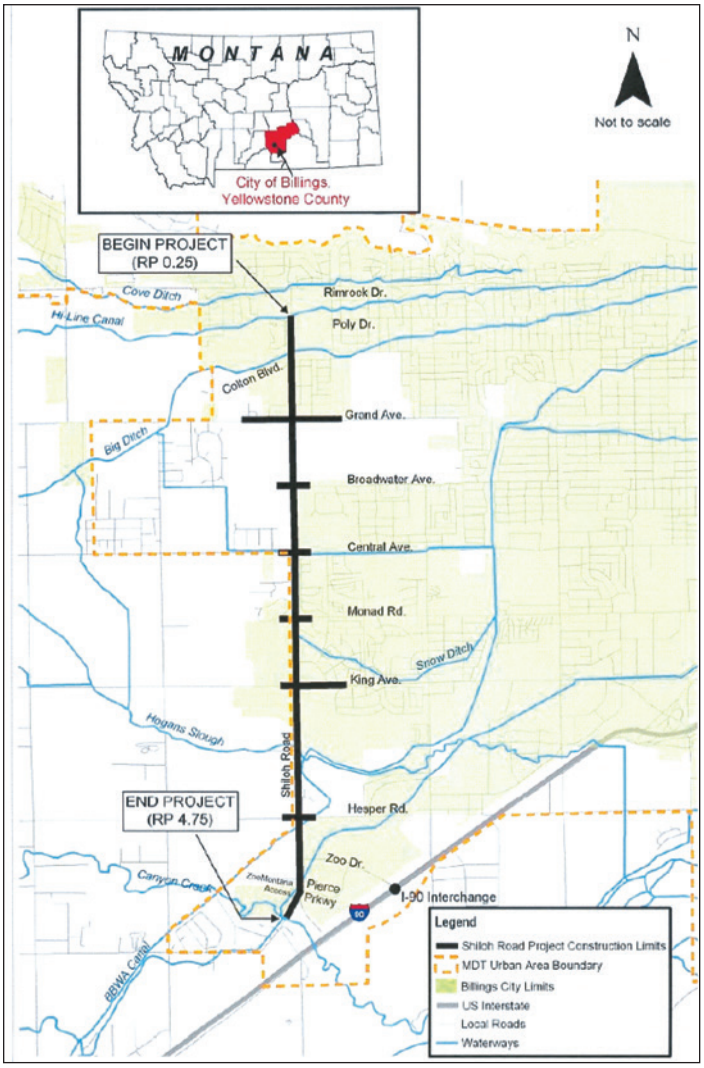
MONTANA'S ROUNDABOUT CORRIDOR

Overview

The Montana Department of Transportation (MDT) reconstructed Shiloh Road to address capacity needs and safety issues. Maintaining a desirable corridor context was a primary factor in the planning and design phases of the project. To incorporate a substantive safety focus into the alternatives, the MDT applied the Diagnosis Crash Analysis, Review Roadway Design Context Considerations, and Countermeasure Development tools.

This case study shows how using safety analysis tools can influence the engineering and design phase so as to incorporate elements that substantively address identified and anticipated safety issues.

Figure 10-8. Shiloh Road Corridor



Source: Shiloh Road Corridor EA, Montana Department of Transportation.

Background and Project Description

Shiloh Road is a 4.5-mile, two-lane roadway built in 1956 between Canyon Creek and Poly Drive on the west edge of the city of Billings in Yellowstone County (figure 10-8). It was a principal arterial that no longer met national design guidelines or MDT design standards. The roadway was characterized by

12-foot lanes, narrow shoulders ranging from zero to 8 feet in width, inadequate vehicle turning radii at intersections, and discontinuous pedestrian and bicycle facilities.

Heavy vehicles regularly travel the corridor to access commercial businesses. Shiloh Road was becoming congested as growth steadily moved westward into rural areas. In a prime area for continued expansion, predicted residential and commercial growth is expected to triple traffic volumes on Shiloh Road from 13,000 to 40,000 vehicles per day in the next 20 years. Some cross streets carry volumes equal to those on Shiloh Road.

The project widened Shiloh Road to a four-lane road with an urban-type footprint. The new road is divided by a raised median. To improve travel for all transportation modes, the project includes eight multilane roundabouts that accommodate heavy trucks and transit vehicles, a continuous sidewalk, a 10-foot detached multiuse path, access control, lighting, irrigation and drainage facilities, and landscaping. Provisions for pedestrians and bicyclists include a pedestrian underpass and an actuated mid-block pedestrian crossing.

The Shiloh Road project was conducted in three phases. Phase I, begun in 2002, included the development of an environmental assessment, which was finalized in 2007. The FHWA issued a Finding of No Significant Impact for the preferred alternative in May 2007. Phase II (design) and phase III (right-of-way acquisitions) were completed simultaneously in 2009. Stakeholder meetings were held regularly throughout the process to involve the public, residents, and business owners in order to produce a solution that fit within the corridor context and to keep them informed about the status of the design effort. Project construction was completed in fall 2010.

Project Purpose and Need

The purpose of the project was to improve mobility and safety along the corridor by addressing roadway and intersection deficiencies; increasing capacity; improving the transportation system linkage; and providing bicycle, pedestrian, and transit improvements. The public and local officials (MDT, City of Billings, Yellowstone County) expressed a strong desire for the improved corridor to fit within the context of the area. Thus, the new roadway needed to be an inviting gateway to the community, to have a minimal footprint, and to be safer for all users.

From a mobility perspective, a need existed to increase capacity and decrease travel time along a corridor serving residential and commercial travel within the community and regionally. Congestion and delay during peak periods of the day typically resulted in a corridor travel time of 15 minutes or more. Roadway deficiencies to be corrected included deteriorating pavement and subgrade, substandard guardrails, inadequate clear zones, insufficient shoulders, absence of turn lanes, and inadequate turning radii.

For the period 1996–2000, 88 crashes were recorded on Shiloh Road within the project area. Most were multiple-vehicle collisions at major intersections. Between 2001 and 2003, 112 crashes were reported in the same area, 60 of which resulted in injuries. Although 80 percent of the 112 crashes were coded as intersection related, most of the remaining crashes occurred near intersections. The predominant crash types during the 3-year period were rear-end and angle collisions. Three of the seven intersections with major road crossings had no turn lanes, likely a contributing factor to the predominant crash types.

No pedestrian or bicyclist crashes were reported, but discontinuous pedestrian and bicycle facilities along the corridor increase the potential for crashes between those users and vehicles. That potential is of particular concern because the neighborhoods bordering Shiloh Road are expected to experience significant population increases. Although the corridor has no transit service, the design needed to provide for it, so future expansion of bus service would be possible in this developing area of Billings.

Safety Tools and Best Practices Used

Diagnosis/Crash Analysis. Application of the safety analysis tool determined that about half of the 112 crashes along the corridor resulted in injuries. A predominant crash type was angle crashes at signalized intersections, which tend to be more severe. Identifying the crash characteristics of the predominant crash types provided the opportunity to focus the application of the Countermeasure Development tool, such that the safety features included in the design would have the greatest potential to prevent or reduce the severity of crashes in the project area.

Review Roadway Design Context Considerations. The strong desire of the stakeholders to achieve a design that fit within a specific context for the corridor influenced the development of alternatives. To address congestion and safety, a four-lane divided highway with signalized intersections was proposed. Turn lanes would address the rear-end collisions that predominated within the two-lane configuration. The resultant footprint, however, did not fit the corridor context, and concerns for safer travel for other users remained. Through the application of this safety analysis tool and the Countermeasure Development tool, a roundabout alternative was developed to achieve a smaller footprint, to improve travel time delay, and to incorporate more safety features to address predominant crash types.

Countermeasure Development. The Countermeasure Development safety analysis tool was applied to identify the safety features of a roundabout and to compare them with the signalized intersection alternative. To incorporate a substantive safety approach, the MDT used national resources to apply this tool and to identify countermeasures that have proved to be effective. Two publications

were referenced during this study: "The Effects of Roundabouts on Pedestrian Safety" by John R. Stone, et al. and "Roundabouts Reduce Traffic Backups as Well as Crashes Involving Injuries" by the Insurance Institute for Highway Safety. Compared with signalized intersections, roundabouts (a) eliminate vehicle crossing conflicts by converting all movements to right turns (address the angle crash issue), (b) promote continuous movement along the primary road (address the rear-end crash and mobility issues), (c) require less right-of-way (fit within corridor context), (d) reduce delay (address congestion and mobility issue), (e) provide aesthetic enhancement opportunities (improve corridor context), (f) provide adequate access control to the corridor (address mobility issue), (g) cost less to construct, and (h) result in fewer environmental impacts.

AASHTO's *Highway Safety Manual*, released after the selection of the preferred alternative for this project, indicates that roundabout conversion is effective at reducing the frequency and severity of crashes. One reason is that drivers typically travel more slowly through roundabouts, which results in lower crash frequencies and lower severities. Table 10-6 shows the safety effectiveness of two roundabout countermeasures and the crash types affected by their application. Other safety countermeasures were included in the design on the basis of their published effectiveness at reducing pedestrian and bicyclist crashes. They include at-grade pedestrian refuge areas in the roundabouts' splitter islands, a detached 10 foot-wide multiuse path along one side of the corridor, a pedestrian-actuated rectangular rapid flash beacon at one mid-block crosswalk, and a pedestrian underpass.

Information about roundabouts can be found in *NCHRP Report 672: Roundabouts—An Informational Guide* (http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_672.pdf).

Preferred Alternative

The preferred alternative is a four-lane roadway with raised medians and eight roundabouts in lieu of signalized intersections. It resulted in part from the application of safety analysis tools to include a substantive safety component in the design and engineering process. In addition to providing a better level of service (LOS), the roundabouts will reduce travel times along the corridor, increase corridor capacity, and reduce the frequency and severity of intersection crashes.

The roundabout alternative required less right-of-way and resulted in a less expensive solution overall (figure 10-9). Furthermore, the stakeholders felt this alternative fit better within the corridor context because of (a) the ability to provide more access control, (b) the landscaping and beautification opportunities provided by the raised medians, (c) the roundabout central islands that provide a more open and less urban feel, and (d) the more pedestrian-friendly crossings at intersections. Improved travel conditions through the corridor would result in better service reliability for future bus routes.

Figure 10-9. Shiloh Road Before (left) and After (right) Project Completion

Source: Federal Highway Administration, Public Roads Magazine.

The typical cross section is two 12-foot travel lanes per direction separated by a raised median that varies in width to accommodate left-turn lanes. In addition to adequate clear zones, the design included street lighting, lighting for the raised medians, and stormwater management. To address safety issues, planners designed the roundabouts to accommodate all modes of travel, including walking, bicycling, transit buses, and trucks.

Pedestrian and bicycle travel is separated from vehicular travel with a variable-width sidewalk on one side of Shiloh Road and a 10-foot multiuse path on the other. Those facilities meet the minimum requirements of the Americans with Disabilities Act. At the roundabouts, users have less exposure to vehicular traffic and shorter crossing times and distances, because they cross

Table 10-6. MDT Implemented Safety Measures

Safety Countermeasure	CMF[a]	Crash Type
Conversion of a two-way, stop-controlled intersection to a modern roundabout	0.56	All crash severities and collision types
Conversion of a signalized intersection to a modern roundabout	0.52	All crash severities and collision types

[a] *Crash modification factor from AASHTO's* Highway Safety Manual.

Figure 10-10. Roundabout

Source: Federal Highway Administration, Public Roads Magazine.

one direction of traffic at a time with refuge areas on splitter islands. This design eliminates conflicts typically encountered with crossing through signalized intersections, such as left turns on green, right turns on green, right turns on red, and red-light-running through vehicles.

The roundabouts were designed for WB-67 trucks to accommodate the corridor's context as a community and regional facility used by the trucking industry. To reduce the potential for sideswipe collisions within the roundabout, the design included a gore delineated by pavement markings (figure 10-10). The gore separates the 2 entry lanes to accommodate off-tracking by large vehicles as drivers enter the roundabout. The gore serves to lower the entry speed, which is beneficial for reducing potential conflicts with pedestrians and bicyclists.

Results

After opening the corridor to traffic in fall 2010, the MDT conducted a preliminary postconstruction evaluation in summer 2011 that focused on operations and not safety. The evaluation shows that the travel times recorded during peak and nonpeak periods for both directions were essentially equivalent during all survey collection periods. At just over 7 minutes, the average travel time to traverse the corridor is now nearly half of what it was. Speed data for the through movements on Shiloh Road were recorded at two locations as part of the operations evaluation. The average recorded speeds at the roundabouts, for which the posted advisory speed is 15 miles per hour, were 19.2 and 17.4 miles per hour.

MDT officials feel that the reconstructed Shiloh Road is meeting expectations with few exceptions. Performance measures such as travel time, speeds, and queues were better than expected. Pedestrian presence is minimal at the roundabouts, and drivers' yield behavior toward pedestrians using the crosswalks exceeded expectations. Several drivers seemed not to yield properly to oncoming traffic, but driver behavior is expected to improve as familiarity with the configuration increases.

To maintain a focus on substantive safety in the Billings area, before–after evaluations could be conducted to assess the effectiveness of the safety countermeasures that were incorporated into the engineering and design phase of the project. The results of that evaluation could inform future planning and programming efforts for transportation improvements in this growing city.

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MERCER CORRIDOR IMPROVEMENTS, SEATTLE, WASHINGTON

Overview

The Seattle Department of Transportation (SDOT) is improving the Mercer Street Corridor to address capacity needs and safety issues. The corridor context is being revised to enhance multimodal travel and to improve mobility along the roadway network. This effort provides an example of using safety analysis tools to influence the engineering and design phase so that a project incorporates elements that can substantively address identified and anticipated safety issues. Diagnosis/Crash Analysis, Review Roadway Design Context Considerations, and Countermeasure Development tools were applied during the engineering and design phase.

This case study illustrates how a substantive safety focus and the use of safety analysis tools contributes to a roadway design that includes safety features intended to proactively prevent certain crash types rather than correcting issues related to a defined crash history at a given location.

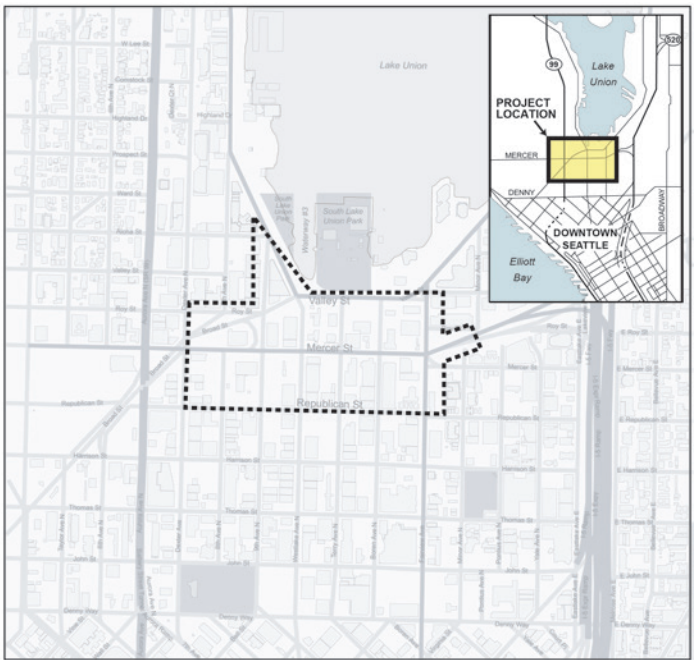
Background and Project Description

The Mercer Corridor project is located in the South Lake Union (SLU) area, just north of downtown Seattle (figure 10-11). Categorized as context zone 4, "general urban zone," the land use consists of light industrial and commercial uses. Initially a temporary solution, Mercer Street and Valley Street were constructed more than 50 years ago as a one-way couplet to provide access to I-5 as it was being built. That vehicle-focused design does not adequately accommodate pedestrian and bicycle traffic.

Recognized as a major bottleneck in the Seattle street system, the area experiences heavy congestion during weekday afternoon peak hours as eastbound traffic accesses I-5 and after special events in the Seattle Center area.

The SLU neighborhood is designated an urban center in the city of Seattle's 2004 Comprehensive Plan. As such, the planned

Figure 10-11. Mercer Corridor Project Location



Source: Seattle Department of Transportation.

growth in the area is projected to add about 200,000 daily person trips by 2030. Seattle policy requires that transportation infrastructure in urban centers accommodate transit, walking, and bicycling *as the primary modes to serve increased travel demand and to accommodate economic growth and neighborhood livability.* The type and density of land use planned for SLU are consistent with context zone 5, "urban center."

As an element of the Alaskan Way viaduct replacement effort, the Mercer Corridor project will connect the Seattle Center and northwestern neighborhoods to the SR 99 tunnel. With the intent to prepare the area as an urban center zone, the project will rebuild parts of the street network and underground utilities and will improve pedestrian and bicycle routes. The Mercer Street–Valley Street one-way couplet will be replaced by widening Mercer Street and providing two-way travel on both streets. Specific provisions for transit are not included in the project. Construction began early in 2010, and completion is expected in late 2017.

Project Purpose and Need

As a result of congestion in the project area, a few key intersections operate at levels of service E and F during peak hours. Mobility is further hindered by the lack of east–west bus service and a sidewalk network in a state of disrepair that does not provide adequate coverage. The project area includes few signalized crosswalks and limited bicycle facilities.

Safety concerns include seven intersections within the study area considered to be high accident locations, because their observed crash frequencies exceed SDOT's minimum threshold of 10 or more crashes per year for signalized intersections and 5 or more per year for unsignalized intersections. Together, an average of 62 crashes per year occurred at those intersections between 2001 and 2003. Angle collision was the predominant crash type. Predominant crash types along the study area segments were rear-end and sideswipe same-direction collisions, for which congestion and frequent lane changing could be contributing factors.

SDOT also identified six sections on I-5 near the project area as high accident locations, because they experienced a higher-than-average rate of severe crashes in a 2-year period. Three of the locations are within the Mercer Street interchange (northbound off-ramp and southbound on- and off-ramps). The congestion in the Mercer Corridor that extends onto I-5 is thought to be a contributing factor to some crashes. The predominant crash types on the northbound off-ramp were rear-end crashes followed by angle and sideswipe collisions. Likewise, the predominant crash type on the I-5 mainline was rear-end.

With regard to other travel modes, at least one pedestrian- or bicycle-related crash was reported at most intersections in the project area within the past 3 years. Those types of crashes occurred at mid-block locations. In the entire study area, 21 crashes involved pedestrians, and 16 involved bicyclists.

According to the city's Comprehensive Plan, most of the projected growth in daily person trips must accommodate the transit, pedestrian, and bicycle transportation modes. Therefore, redevelopment of the Mercer Corridor to accommodate nonmotorized modes and their interaction with the vehicular travel mode in a safe manner was a primary driver for the project. Another driver was the need to improve vehicular mobility so that the Mercer Corridor could retain its function as an east–west arterial serving through traffic and freight to and from I-5.

Safety Tools and Best Practices

Diagnosis/Crash Analysis. The application of the safety analysis tool determined that similar types of crashes involving pedestrians and bicyclists occurred at major intersections throughout the project area during the 3-year analysis period. Identifying the crash characteristics of the predominant crash types provided the opportunity to focus the application of the Countermeasure Development tool, such that the resultant safety features included in the design would have the greatest potential to prevent or reduce the severity of crashes in the project area.

Review Roadway Design Context Considerations. The reconstruction of the one-way couplet provided the opportunity to reconfigure Mercer and Valley Streets in a manner that could accomplish the project purpose of creating an urban center zone through which all travel modes could move safely and efficiently. That change in context suggested that the safety focus be on identifying substantive solutions intended to prevent crashes rather than

on addressing site-specific historical safety issues. The project team recognized that crash prevention would be realized according to how well the increased volumes of pedestrians and bicyclists were accommodated alongside increased east–west vehicular volumes, so the tool was applied along with the Countermeasure Development tool to provide input into the design of the cross sections, intersections, and signal operations for both roads. That input included dimensions for the vehicle, parking, and bicycle lanes; the sidewalks; and the pedestrian refuge areas.

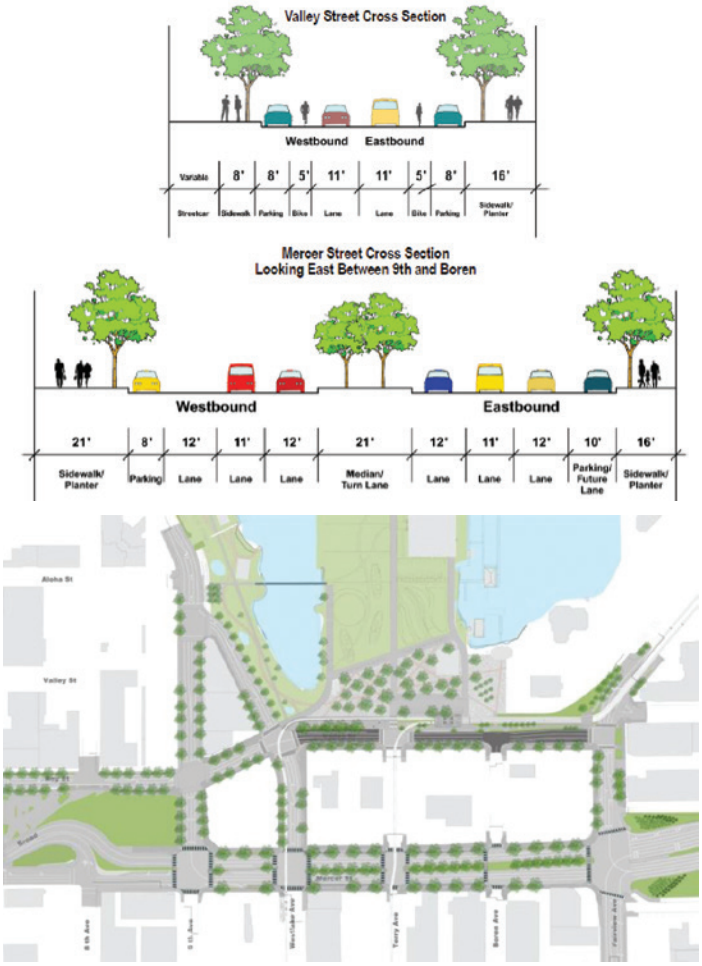
Countermeasure Development

The Countermeasure Development safety analysis tool was applied to identify features that have the potential to reduce crashes involving nonmotorized travelers and that fit within the corridor context. SDOT used national resources to apply the tool. Those resources included published safety effectiveness results and the knowledge base for the design and operation of urban streets and intersections with significant nonmotorized transportation demand. Countermeasures and safety features stated in those resources as being effective at reducing the frequency and severity of nonmotorized crashes were incorporated into the designs for various alternatives.

The countermeasures incorporated into the alternatives generally include (a) separation of bicyclists from high-volume traffic lanes, (b) raised or landscaped medians that serve as pedestrian refuges and focus crossings to intersections, (c) allocation of additional green time in the signal cycle for pedestrians at locations where right-of-way constraints prevent landscaped medians, (d) sidewalks with adequate widths, and (e) vehicle turn movement restrictions at major intersections to eliminate certain vehicle and pedestrian crossing conflicts. Table 10-7 shows the safety effectiveness (CMF) for particular crash types and the national resource for some of the countermeasures incorporated into the alternatives.

Additional information about Seattle's safety efforts can be found on SDOT's website (http://www.seattle.gov/transportation/safety.htm).

Figure 10-12. Preferred Alternative



Preferred Alternative

The preferred alternative emphasizes safe mobility and accessibility for nonmotorized travel while also providing for enhanced vehicular mobility. As shown in figure 10-12, sidewalks and bicycle lanes provide continuous travel separated from moving vehicles for nonmotorized users. The Mercer-Valley couplet is replaced by widening Mercer Street and narrowing Valley Street. Mercer Street will be widened from a four-lane, one-way street to a six-lane, two-way street with a raised median from Fairview Avenue to Ninth Avenue.

Table 10-7. SDOT Implemented Safety Measures

Safety Countermeasure	Crash Modification Factor	Crash Type
Provision of exclusive bicycle facilities	0.96[a]	All segment crashes
Use of 11-foot lanes	1.00[b]	Run-off-road, head-on, sideswipe
Use of landscaped medians as pedestrian refugees >20 feet	0.99[b]	All crashes
Allocation of additional pedestrian green time	0.43[a]	Pedestrian
Provision of continuous sidewalks	0.26[c]	Pedestrian

[a]*Toolbox of Countermeasures and Their Potential Effectiveness for Pedestrian Crashes.*
[b]AASHTO *Highway Safety Manual.*
[c]*Crash Modification Factors Clearinghouse.*

The cross section will include wide sidewalks that accommodate both pedestrians and bicyclists, on-street parking, and a landscaped median with pedestrian refuge areas and left-turn bays. At locations with left-turn bays, the 21-foot-wide median will be narrowed to accommodate the turn lane, but a 10-foot-wide curbed median will still provide refuge for pedestrians and bicyclists unable to cross the entire street width in one traffic signal phase. In locations where a median will not be present because of right-of-way constraints, increased crossing time will be provided for pedestrians and bicyclists. Turn restrictions will be implemented at some intersections on Mercer Street to eliminate conflicts with nonmotorized users.

Valley Street will be narrowed to a two-lane street with 11-foot lanes to encourage lower vehicular speeds and to reduce the severity of potential vehicular crashes with pedestrians or bicyclists. The cross section includes wider sidewalks separated from parking lanes by a landscaping buffer, on-street parking, and 5-foot dedicated bicycle lanes to separate the two travel modes and to reduce the potential for crashes between vehicles and bicyclists. The provision of on-street bicycle lanes is feasible, because Valley Street will be used primarily by low-speed, local traffic (most of the through traffic and westbound truck traffic from I-5 in the project area will be diverted to the two-way Mercer Street). Turn restrictions will also be implemented at some intersections on Valley Street to eliminate conflicts with nonmotorized users.

Risk Management

The project was driven primarily by redevelopment to accommodate economic growth and neighborhood livability. As part of the project development process, SDOT recognized that the resultant changes in context created by the project required a different focus on safety.

The quantitative safety analysis examined various alternatives that resulted in safety-informed decisions. That decision-making process incorporated important risk management principles with regard to documentation of the bases for SDOT's decisions. Should a lawsuit arise alleging that changes to the facility were a cause of injury, SDOT has a solid foundation on which to support the exercise of its discretion and the soundness of the engineering decisions.

Results

The preferred alternative demonstrates the ability to balance vehicular mobility and quantitative safety if both are considered during the engineering and design phase. Some design elements in the preferred alternative work to enhance both substantive safety and mobility. For example, wide, raised, and landscaped medians establish access control, provide space for left-turning vehicles at signals, and focus pedestrian crossings at locations where they can be most safely accomplished: the signalized intersections. Turn restrictions, intersection geometry, and lane widths all promote speeds appropriate for the urban center context. The new Valley Street configuration was explicitly designed to discourage high-speed through traffic and to encourage pedestrian and bicycle traffic.

A two-way Mercer Corridor will improve mobility through more direct movement of traffic and freight through the corridor and will enhance circulation for all transportation modes. An improved pedestrian and bicycle network will reduce conflicts with vehicles. Furthermore, the project is expected to support transit use through improved pedestrian facilities and an enhanced street network that allows east–west transit service. The pedestrian-friendly environment will also connect neighborhoods with the SLU area. The inclusion of quantitative safety considerations in the engineering and design phase of the project contributed to the development of a solution that will enable the area to meet the goals of an urban center zone.

The project demonstrates that the application of safety analysis tools during the engineering and design phase provides the opportunity to incorporate safety features into roadway design, such that its features fit within the corridor context and provide the potential to prevent targeted crash types.

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BROADWAY: UNION SQUARE, NEW YORK, NEW YORK

Overview

The New York City Department of Transportation (NYCDOT) implemented enhancements at Broadway and Union Square to address traffic safety issues. This effort provides an example of using safety analysis tools during the design phase to influence the design of improvements that can appropriately address safety issues. Diagnosis/Crash Analysis and Countermeasure Development tools were applied to provide a data-driven method for selecting enhancements during the planning and design phases.

Project Description

New York's Union Square is one of the most important and historic intersections and public places in Manhattan. The Broadway–Union Square project area is located in Manhattan's Flatiron District. The area is bounded on the south by Union Square and E. 14th Street and on the north by Madison Square and E. 23rd Street (figure 10-13). The streets of Broadway–Union Square West and Park Avenue South–Union Square East form the western and eastern boundaries, respectively. The

Figure 10-13. Union Square Project Area

Source: NYCDOT, 2011 Sustainable Streets Index.

land uses are predominantly highrise mixed-use buildings with ground-floor retail. The area is a major transportation hub with access to several subway and bus lines.

For many years, the community expressed concerns about safety in the area, particularly at the intersection of Broadway–Union Square West and E. 17th Street. Concerns were related primarily to speeding (about 30 percent of vehicles exceeded the 30 miles-per-hour (mph) posted speed limit) and the numerous pedestrian and bicycle crashes that occurred along the corridor. NYCDOT had identified the intersection as being in the top 3 percent of high-crash locations in Manhattan in its annual safety assessment.

Project plans to implement safety-related countermeasures (enhancements) were presented to the community several times to explain the project and to address issues raised by residents and business owners. Suggestions gathered from stakeholders were incorporated into the design alternatives. The proposed safety, greening, and traffic network plan was approved by Manhattan's Community Board 5, and implementation began in summer 2010. Local residents and merchants were involved throughout the implementation process. Construction was completed in 2011.

Project Purpose and Need

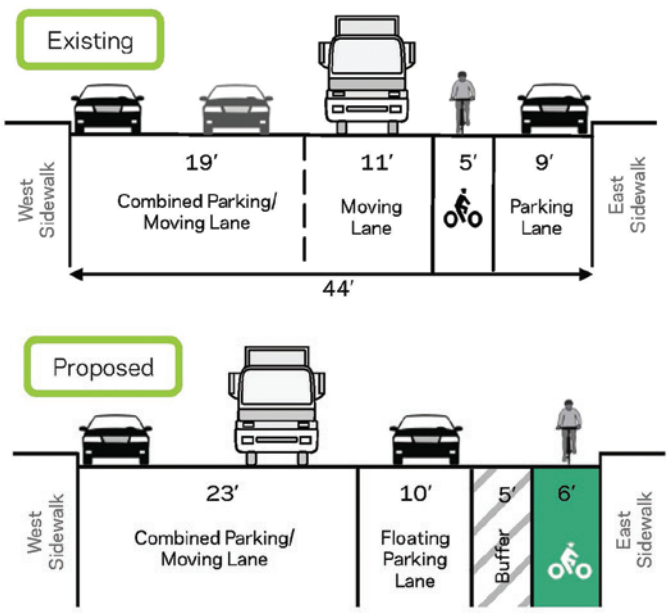
From 2007 through 2010, injuries to 67 pedestrians, 32 bicyclists, and 53 motor vehicle occupants were reported resulting from crashes in the project area. The injury crashes represented 22 percent of the 301 total crashes that occurred during those 4 years. Those safety issues led to reduced mobility and less economic vitality for the area. Therefore, NYCDOT initiated the enhancement project to improve safety, mobility, and economic vitality in the area. A decrease in crashes has the effect of reducing the societal costs associated with the crash itself and the resultant delay in travel time. Furthermore, increased mobility gained by improving traffic flow for all travel modes can attract more people to the area, increase user satisfaction, and prompt growth in retail activity.

Safety Tools and Best Practices Used

Diagnosis/Crash Analysis. Using the Diagnosis/Crash Analysis tool, NYCDOT identified the predominant crash types in the project area. Analysis of the 2007–2010 crash data indicated that the crash types with the greatest frequency and highest severity were pedestrian, bicyclist, and angle vehicle crashes. Those crash types were concentrated at two intersections—Broadway–Union Square West and E. 17th Street, and Union Square West–E. 14th Street—and along Broadway between E. 23rd and E. 18th Streets.

Countermeasure Development. Drawing on the crash characteristics and locations of the predominant crash types, the Countermeasure Development tool identified potential countermeasures to address those crash types. NYCDOT, in coordination with local stakeholders, then proposed implementing proven safety countermeasures to address the area's specific safety issues and the accessibility requests of local business owners.

Figure 10-14. Existing Condition and Preferred Alternative



Source: NYCDOT, "Broadway: Union Square Proposed Safety Improvement" fact sheet.

NYCDOT used the annual *Safe Streets* reports, *Sustainable Streets* reports (which replaced the *Safe Streets* reports), and the *New York City Pedestrian Safety Study & Action Plan*—local sources of proven countermeasures—to apply the Countermeasure Development tool and to develop countermeasures to incorporate into various design alternatives. That performance assessment included several metrics, such as crash type, frequency, severity, vehicle speeds, and retail sales. Use of countermeasures that were proved effective elsewhere in New York City is a good example of incorporating evaluation results into the ongoing planning and programming process.

Preferred Alternative

Several alternatives were eliminated because of business owners' concerns about customer accessibility. NYCDOT selected the preferred alternative on the basis of technical studies and stakeholder input. The preferred alternative emphasized safe mobility and accessibility for pedestrian travel, while providing for enhanced vehicular mobility and the creation of new public plaza spaces.

Figures 10-14 and 10-15 depict the countermeasures provided in the preferred alternative: (a) protected bike paths, (b) landscaped pedestrian safety islands, (c) conversion from two-way to one-way traffic flow, (d) turn bays, (e) curbside turn lanes and turn restrictions to ensure surrounding streets would be able to handle the diverted traffic, (f) pedestrian plaza space, and (g) signal timing adjustments. Those enhancements were designed within the existing roadway footprint.

Figure 10-15. Before and After Photos of the Study Area

Source: NYCDOT.

Risk Management

The project focused on safety at the outset to address vehicle speeds, bicycle crashes, and pedestrian injuries. The project also had the goal of improving mobility and economic vitality. Some alternatives that were considered were rejected as having adverse effects on customer accessibility to local businesses. In the end, the final project reduced total crashes by 29 percent. The project development process in this case produced safety-informed decisions that allowed NYCDOT to consider safety at a level comparable to other design considerations so as not to increase the risk of tort liability.

Conclusions

According to its standard practice, NYCDOT conducted an initial postimplementation evaluation of the enhancements using crash data from October 2010 to September 2012. The results indicated that total crashes decreased by 29 percent, and injury crashes decreased by 23 percent. Injuries to pedestrians decreased 22 percent, injuries to bicyclists decreased 11 percent, and injuries to motor vehicle occupants decreased 52 percent in the project area. Those results are consistent with the project expectations that the enhancements would reduce pedestrian, bicycle, and total crashes.

The total crash reduction exceeded the estimate of 25 percent published in FHWA's *Desktop Reference for Crash Reduction Factors*. The bicycle crash reduction of 11 percent is less than the 35 percent stated in the *Desktop Reference*, but that lower reduction was expected because the published crash reduction factor refers to the addition of a new bicycle lane, whereas this project relocated an existing bicycle lane away from a moving-traffic lane. The pedestrian crashes decreased as expected on the basis of the information in the *Desktop Reference*.

Changes in observed vehicle speeds can be a surrogate measure of change in pedestrian and bicycle crash severity. Speed studies conducted along Broadway showed that the number of drivers exceeding the 30 mph speed limit decreased from 28 percent to 12 percent, and that travel times stayed about the same as before the project implementation. That speed reduction may be correlated to the observed 23 percent reduction in injuries resulting from crashes. Vehicle volumes in the area remained steady, as southbound drivers shifted from Broadway to Park Avenue. Bicycle volumes in the area increased 16 percent on weekdays and 33 percent on weekends. Even though the volume of bicycle traffic increased, bicycle crashes decreased after the implementation of the enhancements.

Stakeholder satisfaction is an important metric for agencies such as NYCDOT. A Union Square Partnership survey indicated that 74 percent of the local residents and business owners were satisfied with the new configuration, with 20 percent of the store owners and managers reporting that they felt the new pedestrian plaza spaces improved business. Key stakeholders indicated that the improvements have greatly benefited the Greenmarket farmers' market.

In summary, the comprehensive redesign of the Union Square area reduced crashes, increased bicycle usage, and improved business conditions without adversely affecting vehicle mobility, thereby fulfilling the project goals of improving safety, improving mobility, and enhancing economic vitality. This project demonstrates that the application of safety analysis tools during the engineering and design phase can lead to the implementation of effective safety solutions.

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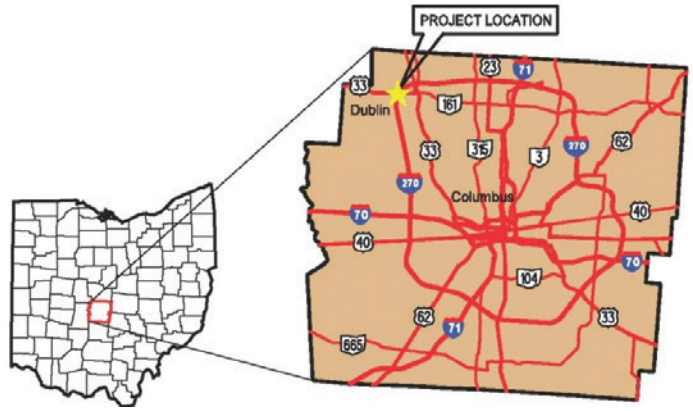
I-270–US 33 INTERCHANGE IMPROVEMENTS, DUBLIN, OHIO

Overview

The Ohio Department of Transportation (ODOT) is reconstructing the I-270–US 33 interchange to accommodate existing and projected traffic volumes. ODOT used the Alternative Analysis with Predictive Models safety analysis tool to estimate the expected safety performance of three alternatives. This case study illustrates how knowledge of potential safety impacts can contribute to the selection of the preferred alternative during the environmental and alternatives analysis stage of the engineering and design phase of a project.

Figure 10-16. I-270–US 33 Project Area



Source: CH2M HILL.

Background and Project Description

Completed in 1973, the I-270 Outerbelt has carried an ever-increasing amount of traffic, particularly as the suburbs around Columbus have grown (see figure 10-16). Rapid population and employment growth near the I-270–US 33 interchange has resulted in dramatic increases in vehicle travel. Daily traffic volumes on I-270 have doubled, and volumes on US 33 have increased substantially.

The I-270–US 33 interchange is a cloverleaf configuration, unique in that it operates as a system interchange to the west but as a service interchange to the east as the highway approaches the Frantz Road–Post Road intersection. Traveling west of the Frantz Road–Post Road intersection toward the Avery Road–Muirfield Drive interchange, US 33 operates as a limited access facility.

ODOT initiated the improvement project by identifying alternative interchange configurations. Elements of the project purpose and need were used in developing and evaluating alternatives, including the no-build alternative. That was accomplished by creating specific measurable criteria to define how well alternatives satisfy the purpose and need elements.

Eight conceptual alternatives were developed. From the initial concepts, alternatives 4, 7, and 8 (figure 10-17) were identified as being best in meeting the project purpose and need. Those alternatives were further refined to provide a phased construction approach to meet the project's goals and funding constraints. The refinements helped facilitate evaluation and comparison to select the preferred alternative.

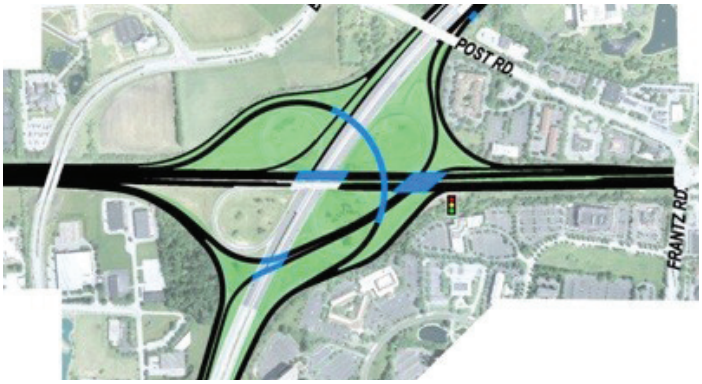
The three interchange alternatives were further developed to meet traffic demands forecast for 2035. Each alternative was designed in accordance with ODOT's *Location and Design Manual* and AASHTO's *Policy on Geometric Design of Highways and Streets,* with the same design criteria applied to each. A comprehensive list of criteria—which included traffic operations (LOS, delay), design and construction requirements, right-of-way needs, capital costs, environmental and community impacts and their mitigation, and safety

Figure 10-17. I-270–US 33 Alternatives Selected for Detailed Evaluation

Alternative 4

Alternative 7

Alternative 8



Source: Recommended Preferred Alternative Report.

performance—was analyzed for each alternative. Thus, predicted safety performance was one of many criteria considered in selecting the preferred alternative.

Final design of the I-270–US 33 interchange was expected to be completed in August 2014, with construction commencing in February 2015.

Project Purpose and Need

The following elements—identified through the evaluation of (a) existing transportation facilities, (b) social and economic conditions of the project area, (c) consultation with affected communities, (d) input from public meetings and the business community, and (e) input from environmental review agencies—defined the purpose and need associated with the I-270–US-33 Interchange:

- Address the current and future traffic congestion in the interchange.
- Resolve existing obsolete geometric designs within the interchange.
- Improve safety conditions within the study area.

Safety Tools and Best Practices Used

ODOT applied the Alternative Analysis with Predictive Models safety analysis tool using the Interchange Safety Analysis Tool–Enhanced (ISATe) to evaluate and compare the expected safety performance of the three alternative configurations. ISATe enables prediction of the safety performance of interchanges (including mainline segments, ramp segments, and ramp terminal intersections) and is the adopted procedure for predictive safety performance of freeways and interchanges according to the AASHTO *Highway Safety Manual* crash prediction methods.

To align with the national emphasis on addressing the fatal and most severe injury crashes, the I-270–US 33 safety performance evaluation focused on predicting the number of KAB crashes (K is a fatal crash, A is an incapacitating injury crash, and B is a nonincapacitating injury crash) to be expected for each alternative between 2015 and 2035. The societal costs associated with the number of predicted crashes over the study period were calculated to be used in the evaluation of the alternatives.

Because ODOT had not yet completed development of calibration factors at the time of the analysis, the ISATe model was not calibrated for Ohio. When assessing the model results, the project team suspected that ISATe was overpredicting possible injury and property damage crashes. The reliability of severe (KAB) crash reporting is generally known in the industry to be greater than that for property damage and lower-level injury crash types, given that there are typically fewer differences in reporting thresholds related to severe injury and fatal crash types. In recognition of that uncertainty, the crash predictions for the property damage and possible injury crashes were not included in the evaluation for the alternatives; alternative analysis was focused on the more reliable fatal and severe injury crashes.

Results

Table 10-8 summarizes the KAB crashes predicted by ISATe and the associated societal cost under each alternative. The ISATe analysis predicted the fewest crashes for the no-build condition during the study period, followed by alternative 8, alternative 4, and alternative 7, respectively.

Further analysis of the predictive model results determined that there are tradeoffs when reconfiguring interchanges with

Table 10-8. Predicted Crashes and Societal Costs: 2015–2035

	KAB Crashes	Societal Costs
No build	308	$97 million
Alternative 4	325	$91 million
Alternative 7	409	$109 million
Alternative 8	320	$89 million

Source: CH2M HILL.

high speed ramp designs. One tradeoff for a higher-quality design is the increased number of vehicle miles traveled through the interchange. The vehicle miles traveled for alternatives 4, 7, and 8 were more than 30 percent greater than for the existing configuration, which in turn would be expected to result in higher crash frequencies than the no-build alternative given the larger area of exposure. Alternatives 4 and 8 were predicted to have fewer KAB type crashes than the no-build alternative and alternative 7, which reduced the overall societal cost for the two alternatives.

Of the three design alternatives, modeling predicted that alternative 8 would have the lowest KAB crash frequency. Subsequent calculations also suggested that alternative 8 would have the lowest expected societal cost.

The criteria evaluation considered the benefits and tradeoffs of each alternative. In collaboration with the city of Dublin, ODOT selected alternative 8 as the preferred choice based on the evaluation of all the criteria.

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APPLICATION AND EVALUATION OF MOTORIST AWARENESS SYSTEM IN WORK ZONES

Overview

The Florida Department of Transportation (FDOT) developed an enhanced maintenance of traffic (MOT) system for highway traffic control in work zones so it could improve motorist and worker safety by alerting drivers to the ongoing activities and characteristics in that work zone. FDOT evaluated the effectiveness of the system during its implementation in active work zones. The MOT system, the Motorist Awareness System (MAS), provides an example of using the Diagnosis/Crash Analysis and Countermeasure Development safety analysis tools in the construction and maintenance phase of project development. This case study illustrates the potential benefits of applying a MAS in work zones on high-speed divided highways.

Background and Project Description

Research indicates that narrow lanes and high speeds are common contributing factors in crash occurrence, particularly in work zones. Lanes are typically narrower than normal through work zones, and speeds are lower than those on the adjacent roadway. Excessive speed and speed variance are the most common contributing factors in work zone crashes of all severities. Transportation agencies across the country have implemented various traffic control devices and countermeasures in an attempt to achieve lower speeds through work zones, but drivers' adherence to them has been minimal, especially during offpeak periods.

To address that issue, FDOT developed a safety countermeasure aimed at improving compliance with work zone speed limits. The MAS builds on the traditional MOT plan that incorporates static advance warning signs and channelizing devices prior to the work zone. FDOT implemented and evaluated the MAS on two Interstate Highways (I-10 and I-95) for 2 years from summer 2005 to summer 2007. The posted speed limits on both facilities were 70 mph before the work zone and 60 mph within the work zone. FDOT evaluated the effectiveness of the MAS in reducing driver speeds approaching the work zones.

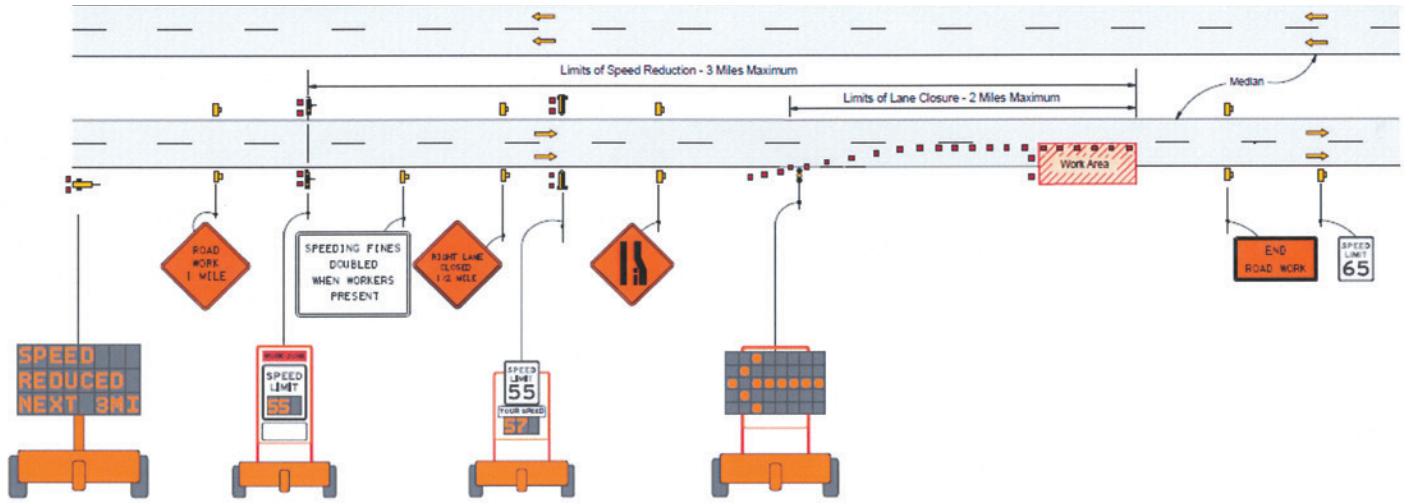
Project Purpose and Need

Designing safer work zones to reduce crashes is a key emphasis area in AASHTO's *Strategic Highway Safety Plan*. In 2005, 137 fatalities and 4,136 work zone crashes were recorded in Florida. The purpose of the MAS project was to develop an effective system to reduce driver speeds approaching and through work zones that could result in reduced crash frequency and improved motorist and worker safety. The goal of the MAS is to achieve the same respect for work zones that Florida's school zones currently receive from drivers.

Safety Tools and Best Practices Used

Diagnosis/Crash Analysis. Using the Diagnosis/Crash Analysis tool, FDOT identified contributing factors to crashes that occur in work zones. An understanding of contributing factors allows safety countermeasures to be developed that can address particular safety issues. The crash data analysis for the MAS project indicated that some of the contributing factors included speeding and distracted driving. Those factors may be attributed, but not limited, to changes in horizontal and vertical alignment approaching the beginning of a work zone, to merging and diverging maneuvers requiring slower speeds, and to a reduced clear zone adjacent to the travel lane. FDOT hypothesized that travel speed through

Figure 10-18: Graphic of Motorist Awareness System



Source: Florida Department of Transportation.

work zones can be considered a surrogate measure of crash potential because higher speeds increase the potential for severe injuries and fatalities resulting from collisions with equipment adjacent to the travel lane or with other vehicles in the work zone.

Countermeasure Development. FDOT used the Countermeasure Development tool to develop a method of traffic control that could address the safety issues identified during the diagnosis effort. As shown in figure 10-18, the MAS augments the traditional static signing and channelizing devices with portable changeable message signs, portable regulatory signs, radar speed-display units, and law enforcement officers who patrol the active work zone area. The MAS does not require the presence of a law enforcement officer, but it can be supplemented with one to improve the reductions in speed.

The MAS is designed for implementation at work zones where (a) the adjacent highway is a multilane facility, (b) the posted speed limit is 55 mph or greater, (c) the work operations require a lane closure for more than 5 days, and (d) the workers are present. To counteract the speeding that contributes to crashes, the portable radar unit displays vehicle speeds at the work zone approaches, and a law enforcement officer can be present to encourage compliance with the posted speed. For the driver distraction issue, the MAS includes portable changeable message signs that alert drivers to the upcoming change in condition for the driving environment and portable regulatory signs that include flashing lights to draw drivers' attention to the posted work zone speed limit.

Evaluating the effectiveness of a safety countermeasure is an important component of the Countermeasure Development tool. It determines if the implemented countermeasure contributed to a reduction in the frequency or severity of the subject crash type. Those results provide the opportunity to fine-tune elements of a countermeasure or its implementation procedure to improve its effectiveness at other locations. Conversely, evaluation results provide the opportunity to eliminate a countermeasure from further consideration if it is proved ineffective.

As part of the project, FDOT evaluated the effectiveness of the MAS using four speed-related performance measures: mean speed, 85th percentile speed, variance of the speed distributions, and proportion of vehicles exceeding the posted speed limit. Between 2005 and 2007, more than 100 speed studies were conducted with the MAS and traditional MOT methods to collect data for Interstate Highway work zones. Speed data were collected at three points for each location: at the work zone approach, within the work zone, and at the work zone exit. The evaluation procedure included four scenarios: traditional MOT, traditional MOT with enforcement, MAS, and MAS with enforcement.

Details about the MAS design, data collection, statistical testing, and conclusions are published in the paper "Evaluation of a Motorist Awareness System," by Peter T. Savolainen, et al. (http://www.workzonesafety.org/files/documents/database_documents/Publication9930.pdf).

Conclusions

According to the four performance measures, statistical tests of the speed data indicate that the MAS was effective at reducing vehicular speeds through construction work zones. Reduced speeds were recorded at the approaches and exits, but speed reductions were greatest within the work zone area. The combination of the MAS with enforcement resulted in additional speed reductions compared with the traditional MOT combined with enforcement scenario. The following defines the speed reductions achieved with the use of the MAS:

- The mean and 85th percentile speeds were consistently lower within the MAS work zones, with average speed reductions of 1.5 to 2.2 mph recorded on I-10 compared with

traditional MOT work zones. Adding enforcement resulted in further reducing the average speeds by 3 to 4 mph.

- Along I-95, the MAS with enforcement produced an average reduction of 4 to 5 mph within work zones compared with traditional MOT with enforcement.
- The use of the MAS along I-10 resulted in less speed variance within work zones compared with traditional MOT. That same reduction was achieved along the two-lane (per direction) segments of I-95. However, speed variance increased within the three-lane work zones, which may have been due to greater traffic volumes and more opportunity for interaction between vehicles because of the greater number of lanes.
- For all scenarios, the MAS work zones resulted in reducing the proportion of drivers speeding within and near the end of the work zones compared with the traditional MOT. The combination of the MAS with enforcement resulted in greater reductions both within and near the end of the work zones.

Those evaluation results suggest that the use of the MAS at construction work zones is an effective countermeasure to address safety issues related to speed and driver distraction. Even though law enforcement officers were not always present during the data collection, speed reductions were achieved because of the other three components of the MAS. Since completion of the evaluation in 2008, FDOT reports that the only revision made to the guidelines was to add the requirement to use the MAS where workers in the work zone are not protected by a barrier.

FDOT reports that 43 work zone fatalities occurred in 2010, 57 in 2011, and 51 in 2012 (the crash form changed at the end of 2011, which could account for the increase in numbers coded to work zones for 2011 and 2012). FDOT believes the use of the MAS contributed to the reduction in fatalities, proving its hypothesis that reduced speeds could lead to fewer crashes and associated fatalities. This case study demonstrates the practical application of safety analysis tools during the construction and maintenance phase of project development.

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RUSSELL STREET SAFETY ANALYSIS, MISSOULA, MONTANA

Overview

The city of Missoula, in coordination with the Montana Department of Transportation (MDT), completed a traffic analysis as part of the production of an Environmental Impact Statement for improvements to the Russell Street and South 3rd Street corridor. The analysis was partially triggered by the public's assertion that the preferred alternative, selected earlier in project development, did not sufficiently address livability goals to achieve a corridor designed to connect all travel modes.

The analysis was performed using the Alternative Analysis with Predictive Models safety analysis tool for the purpose of analyzing the safety performance of the Russell Street design alternatives proposed in the EIS.

This case study illustrates how crash prediction during the design phase can give officials and stakeholders a better understanding of the tradeoffs among various design features. The study also illustrates how the inclusion of transportation system management and operations considerations during the design phase of project development increases the likelihood of achieving sustainability and livability goals.

Background and Project Description

The study area is in the city of Missoula (figure 10-19), which is home to the University of Montana. The city has a population of roughly 60,000. Population growth has averaged 1.4 percent annually and is expected to continue to grow steadily.

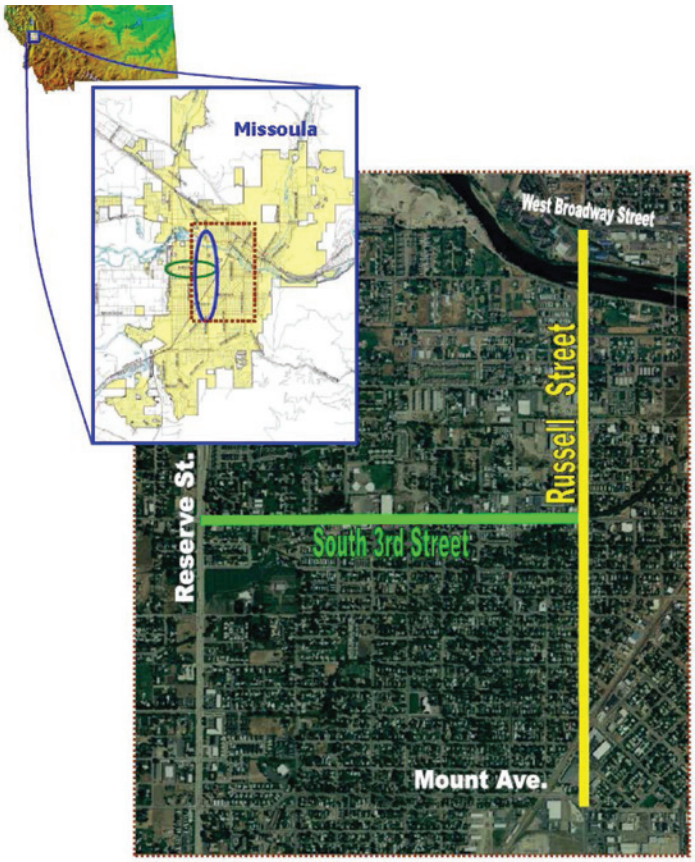
Russell Street is a principal arterial with cross sections that vary from two to four lanes and turn lanes at some intersections. A two-lane bridge crosses the Clark Fork River. South 3rd Street is a collector with one lane per direction and turn lanes at some intersections. Although the corridor serves as an important route for pedestrians and bicyclists in the collegiate community, pedestrian and bicycle facilities are discontinuous within that corridor.

The preferred alternative in the EIS, completed in 2011, recommended that Russell Street be reconstructed as a five-lane roadway with a divided median, a center two-way left-turn lane, and signals at the major intersections. (Additional information about the Russell Street and South 3rd Street EIS project can be found on the MDT website, http://www.mdt.mt.gov/pubinvolve/russell/.)

A group of Missoula residents opposed that recommendation and advocated a three-lane roadway with roundabouts at major intersections. Part of the public's reaction to the preferred alternative was a concern for pedestrian and bicyclist safety on a five-lane roadway with large signalized intersections. The public desire for the design of this corridor is (a) to integrate operational improvements that fit within the scale of the urban area and (b) to enhance safety and the overall multimodal travel experience for pedestrians, bicyclists, and trail and transit users.

The opposition centered on the concern that the corridor management focus was too narrowly aimed at vehicular mobility and not on a viable interconnected system that accommodated all transportation user modes. Furthermore, the local travel demand model was updated through the regional planning process soon after the draft EIS was submitted, thus outdating the original traffic analysis. Hence, the MDT and the City of Missoula

Figure 10-19. Russell Street Project Area



Source: Montana Department of Transportation, Final Environmental Impact Statement.

undertook a new traffic analysis performed for the environmental study with the intent of incorporating the new traffic forecasts into a detailed traffic operational analysis and of incorporating quantitative performance measures for safety of nonmotorized transportation users. The analysis results were integrated into the updated environmental documentation.

As part of that more comprehensive traffic analysis, the Russell Street Safety Analysis project predicted the average crash frequency for seven alternatives divided into two scenarios: one for a three-lane cross section and the other for a five-lane cross section. On the basis of the travel demand model forecasts, different average daily traffic volumes were assumed for each cross section. Each alternative offered a different mix of traffic control types; only one alternative included signals exclusively. The alternatives include the five from the draft EIS (which includes the no-build alternative) and two additional options developed as part of the new traffic analysis.

Safety Tools and Best Practices Used

The Alternative Analysis with Predictive Models tool was applied using AASHTO's *Highway Safety Manual* predictive methods to estimate the total number of crashes for each of the six build alternatives. The total number of predicted crashes is the sum of the predicted average crash frequencies for each intersection and each roadway segment within the alternative. During the study, the MDT had yet to complete the determination of State calibration factors for the predictive method. Such factors account for unique aspects of crash databases, reporting levels, terrain, climate, and demographics associated with each State. Therefore, HSM default values were used for the crash prediction effort.

The no-build condition (alternative 1) was used as a benchmark to determine the estimated percentage of crash reduction for the six build alternatives. The percentage of crash reduction was calculated by comparing the predicted number of crashes for each alternative with the no-build alternative. That comparison provided the opportunity to determine which build alternatives could provide the greatest reduction in crash frequency. Alternative 1 was analyzed with both the three-lane and five-lane scenarios to facilitate its use as a benchmark for comparison with the six build alternatives.

Results

Table 10-9 lists the percentage of crashes under alternative 1 (no build) as 100 because it is the benchmark for comparing the safety performance of the six build alternatives. The percentages shown for the other alternatives represent the number of predicted motor vehicle crashes in proportion to the number predicted for the no-build alternative. The HSM does not provide predictive methods for pedestrians and bicyclists at roundabouts; therefore, a comparison among alternatives was not feasible. In recognition of public concern regarding those travel modes, user ease and comfort with the alternatives were estimated using *Highway Capacity Manual* methodologies for pedestrian and bicyclist LOS.

Alternatives 2, 3, and 5-R have the lowest predicted percentages of crashes, indicating that they provide the greatest reductions in crash frequency compared with the no-build alternative. The primary reason for the lower number of predicted crashes is those three alternatives include roundabouts at the major intersections in lieu of traffic signals. Converting signalized intersections to roundabouts has been an effective countermeasure to lower crash frequency and severity, to reduce speeds, and to reduce the number of conflict points.

Table 10-9. HSM Analysis Results for Russell Street Safety Analysis Alternatives

	Three-Lane Scenarios				Five-Lane Scenarios			
	Alt. 1	Alt. 2	Alt. 3	Option 6	Alt. 1	Alt. 4	Alt. 5-R	Option 7
Percentage of crashes compared with no-build scenario	100	67	65	85	100	70	63	73

Source: Casey Bergh and Nick Foster, "Predicting Crashes the HSM Way: (Almost) Everything You Need to Know."

The smallest reduction in crashes (highest percentage of crashes compared with the no-build alternative) is predicted for option 6. That finding can be attributed primarily to the absence of raised medians, which serve to reduce the number of conflict points with Russell Street through traffic by restricting driveway and intersection access to right-in or right-out only.

Conclusions

This traffic analysis provided the opportunity to analyze the EIS alternatives from a substantive safety perspective. Use of the HSM predictive models with factors calibrated to local conditions would have increased the accuracy of the predicted number of crashes for each alternative. However, use of the default factors in the analysis still provided an opportunity to make relative comparisons between alternatives. Incorporating substantive safety in that manner provided information that the MDT could use to communicate to the public the tradeoffs among the alternatives. This traffic analysis also provided the opportunity to revisit the transportation system management concepts for the corridor by introducing two options that included roundabouts that could help improve vehicular mobility while improving travel conditions for other modes, such as pedestrians, bicyclists, and trail and transit users.

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K-99 IMPROVEMENT PROJECT, WABAUNSEE COUNTY, KANSAS

Overview

The Kansas Department of Transportation (KDOT) performed safety planning to identify enhancements that could be incorporated into the design for a resurfacing project implemented during the maintenance phase of project development. The Diagnosis/Crash Analysis, Countermeasure Development, and Alternative Analysis with Predictive Models safety analysis tools were used during the safety planning process to diagnose the substantive safety issues and to identify countermeasures that were implemented through the maintenance program. The project also included a review of the corridor's horizontal and vertical alignments to determine required improvements from a nominal safety perspective. This effort shows how safety analysis tools can be used to incorporate safety activities into multiple phases in project development, specifically maintenance and systems preservation, and engineering and design.

Background and Project Description

State Highway K-99 is a two-lane, minor arterial that extends from north to south across Kansas. The project area is a 9.6-mile segment of K-99 located between Interstate 70 and 4th Street in the city of Wamego. The land use in the corridor is primarily residential and industrial north of the Kansas River and agricultural to the south. K-99 carries 3,400 to 4,600 vehicles per day and is expected to carry 4,500 to 5,900 vehicles per day by 2035. Most of the intersecting roads are local, gravel roads.

The road is characterized by inadequate narrow shoulders and numerous box culvert drainage structures that lack guardrail protection, even though they are near the roadway within the clear zone. In some locations, the foreslopes are steeper than 4:1 with nontraversable ditch sections. Several horizontal and vertical curves do not meet current design criteria for the posted 65-mph speed limit. Moreover, the local Caterpillar plant located in Wamego recently began manufacturing large mining vehicles. Local stakeholders have expressed concern that oversize vehicles of up to 20 feet wide will affect safety and mobility within the study area.

The initial phase of the project design included the resurfacing effort along with substantive safety improvements. A later phase will involve designing nominal safety improvements so the reconstructed corridor will meet current design criteria. The preliminary environmental screening effort assumed that most, if not all, work would be completed within the existing right-of-way and was likely to result in only minor impacts to environmental resources, with no potential for a significant impact. The K-99 discovery report was submitted in July 2012, and the 1R resurfacing project was completed in 2013.

Project Purpose and Need

The goal of the project was to improve mobility and safety by modernizing the geometry and cross section to achieve compliance with current design criteria. Reported crash data for 2006–2010 indicate that 114 crashes occurred in the project area. Two of the crashes resulted in fatalities and 26 in injuries. The crash rate is nearly 50 percent greater than the statewide average for similar roadways during the same period. That crash history suggests a need to incorporate safety features into the resurfacing project that will reduce the frequency and severity of crashes along that segment of K-99. Because KDOT desired to obtain the maximum possible return on its investment and to minimize impacts, those potential improvements needed to fit within the existing right-of-way and the scope of a resurfacing project.

Safety Tools and Best Practices Used

Both nominal and substantive safety planning processes were incorporated into the project. From a nominal perspective, the requirements to modernize that section of K-99 were assessed. The assessment indicated that improvements to upgrade both horizontal and vertical alignments to current criteria (that is, to make them nominally safe) would require reconstructing more than half of the 9.6 miles. Various realignment options were analyzed, and three were recommended for further evaluation in a subsequent phase that will involve planning the long-term modernization project.

The substantive safety planning process included a quantitative analysis conducted with safety tools to evaluate the predicted safety performance (potential to reduce the frequency and severity of crashes) of a variety of safety enhancements. The following text describes the use of those tools.

Diagnosis/Crash Analysis. The safety analysis tool was applied during the project planning process to identify the most common crash types in the project area. The analysis results showed that run-off-the-road crashes were the most common crash type, representing one-third of the 114 total crashes. Impairment from alcohol, drugs, or medication was a contributing factor in 37 percent of the crashes. Those findings informed the application of the Countermeasure Development safety analysis tool.

Countermeasure Development. The analysis tool was used to identify countermeasures that could address the predominant run-off-the-road crash type. At the onset of the application of the tool, KDOT chose to implement proven, low-cost safety countermeasures and used a national resource—AASHTO's *Highway Safety Manual*—to identify them. The potential countermeasures were selected for analysis with a predictive model, because they could be incorporated into the resurfacing project with minimal additional cost and because studies have shown that they reduce the frequency and severity of run-off-the-road crashes. Table 10-10 lists the potential countermeasures identified through the application of the safety analysis tool.

Alternative Analysis with Predictive Models. The safety analysis tool was applied using FHWA's IHSDM crash prediction module. The module, which implements the HSM predictive methods, was used to predict the percentage of crash reduction that could be achieved with each countermeasure. The 9.6-mile length was divided into three segments for analysis purposes (figure 10-20). The analytical results for existing conditions were used as a benchmark from which to calculate the anticipated percentage of crash reduction for the potential countermeasures. HSM calibration factors specific to two-lane rural roads in Kansas were applied during the analysis. Such factors account for the unique aspects of crash databases, reporting levels, demographics, terrain, and climate associated with each State.

Table 10-10. Crash Prediction Evaluation Results

Safety Enhancement	Predicted Crash Reduction
Segment 1: 3.39 miles	
Paved shoulders of 2 feet	3.8%
Centerline rumble strips	1.8%
Shoulder rumble strips	16.4%
Automated speed feedback	45.5%
Segment 2: 2.75 miles	
Paved shoulders of 2 feet	3.1%
Centerline rumble strips	2.0%
Shoulder rumble strips	16.1%
Automated speed feedback	46.2%
Superelevation improvements	26.9%
Segment 3: 3.45 miles	
Paved shoulders of 2 feet	0.1%
Centerline rumble strips	2.1%
Shoulder rumble strips	16.2%
Automated speed feedback	45.9%

Source: Kansas Department of Transportation.

As reported in the "Preliminary Study of Actions Report," Table 10-10 summarizes the results of that substantive safety analysis. The safety performance evaluation predicts that all potential countermeasures would reduce crashes compared with the existing baseline. The percentages of crash reduction ranges vary widely among the countermeasures.

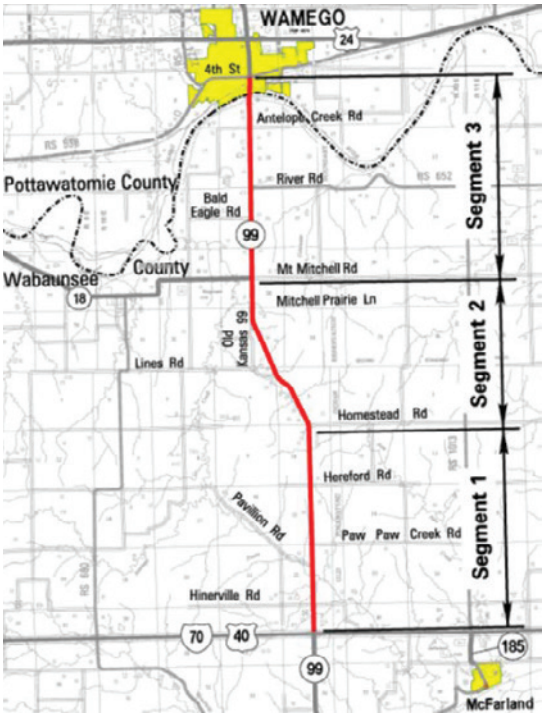
Preferred Alternative

After a review of costs, crash reduction potential, and impacts of different environmental and transportation performance considerations, the countermeasures of 2-foot shoulders and variable 3:1 or flatter slopes were selected as the short-term solution to the geometric deficiencies. On the basis of the substantive safety analysis results, all the countermeasures that provide the opportunity to reduce the frequency and severity of crashes (automated speed feedback, superelevation improvements, and shoulder rumble strips) were recommended for inclusion in the resurfacing project.

Risk Management

KDOT studied a 9.6-mile section of K-99 to assess whether its safety performance could be improved as part of a resurfacing project that did not require any additional right-of-way. An initial analysis to bring the segment up to current standards—and thereby achieve nominal safety—would have required reconstructing 50 percent of the section. Dividing the 9.6 miles into three segments and using quantitative safety

Figure 10-20. K-99 Project Area



Source: Kansas Department of Transportation discovery report.

analysis tools, helped with measuring the effects of various safety enhancements within the right-of-way. The result was a project that significantly enhanced the highway's substantive safety without the added cost of reconstructing the highway to nominal safety standards.

Quantitative safety analysis tools informed the decision-making process and made it transparent. The well-documented and data-driven objective decisions demonstrated effective risk management techniques.

Conclusions

Quantitative safety analyses were conducted to evaluate the predicted safety performance (crashes and their severity) of a variety of safety enhancements. Consulting national resources resulted in the identification of countermeasures that are proven to be effective, that have a low implementation cost, and that fit within the right-of-way. Inclusion of quantitative safety methodologies in the planning process gave KDOT the opportunity to make an informed decision about which countermeasures to include in the K-99 resurfacing project.

To maintain a focus on substantive safety in Kansas, KDOT could conduct before–after evaluations that would assess the effectiveness of the safety countermeasures that were incorporated into the project design. The results of the evaluation could inform future planning and programming efforts for transportation improvements along this corridor and similar corridors in the State.

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APPENDIX: SUBSTANTIVE SAFETY CONSIDERATIONS

Table A-1. Substantive Safety Considerations: Controlling Criteria

Design Element	Substantive Safety Principles	Typical Safety Effects
Selection of design and operating speed (posted speed limit)	The known relationship between safety and design features needs to be considered when selecting design feature values. The operating speed should support the roadway design and its intended function in the overall roadway network and should appreciate the effects on safety performance as a result of changes in design elements.	The selection of design feature values varies according to the operating speed of the facility. Several trends in safety performance can be affected on the basis of operating speed and differences in design features. • The relative proportion of severe crashes increases where higher speed is involved. • Posted speeds set at lower levels encourage drivers to make turning movements at lower speeds. That strategy reduces the frequency of total and roadside fixed-object crashes.
Speed consistency	Design speed affects many design elements. • Design speeds should be established considering the need both to meet driver expectation and to provide for design consistency within the project area and with adjacent roadway segments. • The design speed should feel reasonable for most drivers traversing the roadway section, which will encourage a consistent speed throughout the project.	Lower speeds can produce decreased crash frequency and severity, but crash risk also increases with increases in speed differential (i.e., between vehicles in the same traffic stream or between adjoining sections).
Lane width	The primary safety issues with reductions in lane width are crash types related to lane departure, including run-off-the-road crashes. Wide lanes are beneficial to substantive safety for two primary reasons: • Wide lanes increase the average separation between vehicles in adjacent lanes. • Wide lanes provide more room for driver correction in near-crash circumstances. • On urban arterials with posted speeds 45 mph or less there is no substantive safety benefit between 10, 11, and 12-foot lanes.	Lane width affects safety differently for varying roadway types. It is a factor in safety performance for rural two-lane, two-way roadways and rural multilane highways, but not for urban and suburban arterials. Crash modification factors (CMFs) for lane width are established on average annual daily traffic volume and generally predicted the number of crashes increases with decreased lane width and with increased average annual daily traffic volume. • On high-speed, rural two-lane highways, the risk of cross-centerline head-on or cross-centerline sideswipe crashes increases with decreasing lane width, affecting driver ability to stay within the travel lane. • For two-lane, two-way roadways, lane widening will reduce crash frequency. The effects of that reduction begin to diminish between 11 and 12 feet, with the effects of widening more than 12 feet being negligible.
Combination lane and shoulder width	The allocation of the total paved width between lanes and shoulders can affect the safety of a roadway facility. Speed is also a primary consideration when evaluating potential adverse effects of roadway width on safety. Narrower lanes may encourage lower speeds. Wide shoulders help errant drivers recover and return to the travel lanes.	An increase in the total paved width leads to a reduction in all types of crashes except pedestrian crossing crashes.

Table A-1. Substantive Safety Considerations: Controlling Criteria *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Shoulder type/ design	• Paving a shoulder is preferred to maximize safety effects. The preference for other types in descending order is gravel, composite, and turf. • Shoulders should be designed to be traversable with no edge dropoffs and to provide adequate drainage.	• The trends show that paved shoulders have the fewest crashes, followed by gravel, composite, and turf. The *Highway Safety Manual* (HSM) provides a CMF table for those shoulders on the basis of type and width. • Shoulder Safety Edge℠ avoids a dropoff that could lead to loss of control. The Empirical Bayes evaluation published in *Safety Evaluation of the Safety Edge Treatment* (FHWA-HRT-11-024) concludes the treatment led to a reduction in total crashes on two-lane highways. The benefit–cost ratio on two-lane roads is generally high because of the low implementation cost.
Shoulder width	The presence and width of shoulders influence crash occurrence. On any high-speed roadway, the primary safety issues with reduced shoulder width are crash types related to lane departure, including run-off-the-road crashes. • Shoulder widths should be sufficient for roadway function and operating speed. • Shoulder width should be sufficient to accommodate a disabled vehicle, so it does not infringe the travel way. • The shoulder serves more safety purposes when it is wide enough to accommodate a vehicle, so that it is completely out of the travel lane.	Vertical pavement edges are a recognized detriment to safety, contributing to severe crashes that frequently involve rollovers or head-on collisions. • On rural highways, lack of shoulders can increase off-road crashes. Increases in shoulder width result in a reduction of crash frequency for all crash types. • On high-speed roadways with narrow lanes that also have narrow shoulders, the risk of severe lane-departure crashes increases. Drivers on rural two-lane highways may shift closer to the centerline as they become less comfortable next to a narrow shoulder. Alternatively, when encountering oncoming traffic, drivers tend to shift closer to the shoulder edge and are at greater risk of driving off the paved part of the roadway (and over potential edge dropoffs).
Horizontal curves	The substantive safety performance of a roadway is influenced by the presence and design characteristics of horizontal curvature: • Longer curve length, longer curve radii, and spiral transitions for shorter-radius curves are preferred. • In urban conditions, superelevation is not an influencing factor on substantive safety. • Curves in and through intersections should be avoided or minimized whenever possible. • Design should avoid starting and ending horizontal and vertical curves at the same point.	The horizontal curve influences driver behavior. Other factors contributing to substantive safety of curves includes the cross section and character of the roadside through the curves. • Crash risk on a roadway segment increases with the presence of a horizontal curve. • Drivers make more errors on horizontal curves adjacent to vertical curves, particularly crests that obscure downstream horizontal curves. • Drivers make more errors when curves are combined with other elements, especially intersections. • The probability of a crash occurring on a curve generally decreases with longer curve radii, longer horizontal curve length, and the presence of spiral transitions. • In general, crashes increase when a curve is present. • Horizontal curves with substandard superelevation tend to have higher frequencies of run-off-the-road and loss-of-control crashes. The point of reference is the AASHTO design criteria. Crash frequency increases with increases in variance. • Short sharp horizontal curves are associated with higher crash frequencies (FHWA, *Strategic Highway Safety* Plans, 2013). • Short horizontal curves at sharp crest vertical curves are associated with higher crash frequencies. • Crash frequency increases with decreasing horizontal curve radius and increases with grade difference. Excessive spiral length can have a detrimental effect on safety. The most desirable spiral length is equal to the distance traveled during the steering time, thus ensuring optimal operating conditions for drivers.

Table A-1. Substantive Safety Considerations: Controlling Criteria *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Successive horizontal curves	• Reverse horizontal curves should have adequate superelevation transition between successive curves. • Design should avoid consecutive curves in the same direction, spaced closely together. • Successive curves should be separated by tangent sections where feasible.	• Maneuvers resulting from the driver's need to suddenly correct for behavior because of an unexpected alignment can increase the potential for crashes. Insufficient transitions between curves contribute to what a driver may perceive as a geometric inconsistency. • Use of tangent areas for superelevation transition between successive curves reduces the likelihood of lane-departure crashes. • Successive curves with short transition radii do not produce an unexpected driving condition. However, a long tangent section followed by a sharp curve will generally be perceived as an unexpected condition or geometric inconsistency by the driver.
Superelevation	Horizontal curves are superelevated to reduce the friction demand and steering effort required of the driver. The superelevation on high-speed horizontal curves helps drivers maintain control, thereby reducing the likelihood of lane-departure crashes.	• The HSM has a CMF for superelevation on two-lane rural roads. On other facilities, the effect on crash frequency related to superelevation is unknown. • In urban conditions, superelevation is not an influencing factor on substantive safety.
Traffic control devices	There are several basic traffic control treatments road agencies can consider to aid in keeping vehicles on the roadway through horizontal alignment shifts: • Centerline marking • Edge line marking • Optical speed markings • Horizontal alignment signs • Advisory speed plaques • Combination horizontal/advisory speed signs • Arrow signs • Curve speed signs • Chevron alignment signs • Delineators Enhanced traffic control treatments include the following: • Larger signs/devices • Doubling signs/devices • High retroreflective intensity and fluorescent yellow sheeting • Flashing beacons • Thermoplastic pavement markings • Raised pavement markers • Longitudinal rumble strips	CMFs available from the FHWA Clearinghouse present effectiveness levels for various horizontal curve treatments: • Installing chevron signs, curve warning signs, and/or sequential flashing beacons can result in a reduction in all fatal and injury crashes. • Installing chevron signs on horizontal curves can produce a reduction in nonintersection fatal and injury crashes. • Installing new fluorescent curve signs or upgrading existing curve signs to fluorescent sheeting can result in a reduction of nonintersection fatal and injury crashes. • Providing static combination horizontal alignment/advisory speed signs can generate a reduction in all injury crashes. CMF Clearinghouse (search "horizontal curve"), http://www.cmfclearinghouse.org/; longitudinal rumble strips. *NCHRP 641: Guidance for Design and Application of Shoulder and Centerline Rumble Strips* documented reductions of head-on and fatal and injury crashes on rural two-lane roads from the use of centerline and shoulder rumble strips.
Sight distance criteria	• Roadway designs that provide adequate sight distances around natural and built (existing and anticipated) obstacles enhance safety performance. • Criteria consider the perception and reaction time of the user, given the roadway context and conditions that the user might encounter. • Sight distance criteria provide for visibility of all modes, both to see and to be seen by vehicular traffic. • Criteria incorporate differences in day/night visibility. • Criteria consider needs for visibility of vehicles, temporary traffic control devices. • Criteria account for full range of sight distance requirements: stopping, intersection, passing, or driver decision for a complex maneuver.	Inadequate sight distance will increase the frequency of crashes. Severity depends on the roadway type, roadway features, and relative speed of travel.

Table A-1. Substantive Safety Considerations: Controlling Criteria *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Pavement surface—stopping distance	The pavement surface should have the appropriate friction characteristics to allow drivers to stop or steer on curves when the pavement is wet.	• Pavement resurfacing can improve skid resistance in locations where a high percentage of crashes occur on wet pavements or curves in the roadway. That action may also improve safety by eliminating ruts, potholes, and bumps that contribute to crashes. • Refinishing pavement with a microsurfacing treatment results in a reduction in all fatal and severe injury crashes.
Grade	Grades should not require heavy vehicles to slow and create speed differential. Where necessary, passing lanes should be included in climbing sections. Steep downgrades require longer stopping distances for heavy vehicles.	• Crash risk increases with increases in the speed differential between vehicles in the same traffic stream or between adjoining sections. • For rural two-lane facilities, a steep grade can be expected to increase crash frequency. • Although a similar trend toward increased crashes with increased grades would be expected for other roadway types, the effect on other roadway types is generally undefined.
Vertical curvature	Vertical curves provide a smooth transition between different grades. Vertical curves must be flat enough to provide the sight distance required for drivers to react to the conditions on the road.	• On crest vertical curves the pavement surface limits the driver's view of the road ahead. Lack of required sight distance limits the driver's perception and reaction time, which can result in several types of crashes if the driver cannot stop or maneuver the vehicle. • Sag vertical curves that are shorter than the criteria limit the distance of the headlight beam and reduce the sight distance in low-light conditions. Lack of required sight distance limits the driver's perception and reaction time, which can result in a crash if the driver cannot stop or maneuver the vehicle accordingly.
Vertical clearance	Overhead structures should be 1 foot higher than the tallest vehicle on the road. Designated routes need additional clearances for specially permitted oversized loads.	• Impacts to low structures can cause damage to vehicles and occupant injuries. Structural damage can result in unexpected debris on the road that could create safety issues for drivers.
Combination features of horizontal and vertical alignment	Horizontal and vertical alignment elements should complement each other: • Horizontal and vertical alignments at the intersections or on approaches to intersections should be consistent with visibility requirements approaching and through the intersections. • Combinations should be avoided that will make it difficult for drivers to read the characteristics of the road. • Combinations should be avoided that create excessive vertical or lateral forces that could cause skidding or loss of contact between the vehicle and pavement (for example, tight curve on a downgrade).	• Overlapping crest curves on horizontal curves generally make the horizontal curvature appear sharper and encourage the tendency to drive slower, decreasing crash risk. • Overlapping sag curves on horizontal curves generally make the horizontal curvature appear less sharp and encourage the tendency to drive faster, increasing crash risk. • Combinations of minimum values of different features, such as horizontal and vertical curves can, result in loss of control leading to increases in crashes from lane departure.
Cross slope on tangent alignments	The combination of longitudinal and transverse slopes on the pavement should be adequate so the driver can comfortably maintain the vehicle's position in the lane.	• Insufficient cross slopes can lead to lane departure or run-off-the-road crashes. • Cross slopes that are too steep can cause drivers to drift, skid laterally during braking, or lose stability while traversing the crown during lane-changing maneuvers.
Drainage—cross slope	The combination of longitudinal and transverse slopes on the pavement should be adequate to provide efficient stormwater drainage to prevent ponding, sheet flow, and so forth.	• Water on the pavement can lead to loss of friction, increasing the potential for the driver to lose control of the vehicle at high speeds and leading to several crash types. • In cold climates, water on the pavement can result in icy spots that reduce friction between the vehicle and pavement, leading to several crash types.
Lateral offset to obstruction	Offset to vertical roadside elements should be sufficient that they do not affect a driver's speed or lane position.	• Permanent obstacles adjacent to the road can increase the occurrence of fixed-object crashes when drivers depart the traveled way.

Table A-2. Substantive Safety Considerations: Other Key Elements

Design Element	Substantive Safety Principles	Typical Safety Effects
Cross Section		
Road diet—roadway width/cross section	The classic roadway reconfiguration, commonly referred to as a "*road diet*," involves converting an undivided four-lane roadway into three lanes made up of two through lanes and a center two-way left-turn lane. The reduction of lanes allows the excess roadway width to be reallocated for other uses, such as bike lanes, pedestrian crossing islands, and parking.	Road diets have multiple safety and operational benefits for vehicles as well as pedestrians, such as the following: • Decreasing vehicle travel lanes for pedestrians to cross, thereby reducing the multiple-threat crash for pedestrians, as when one vehicle stops for a pedestrian in a travel lane on a multilane road, but the motorist in the next lane does not, resulting in a crash. • Providing room for a pedestrian crossing island. • Improving safety for bicyclists when bike lanes are added; such lanes also create a buffer space between pedestrians and vehicles. • Providing the opportunity for on-street parking (also a buffer between pedestrians and vehicles). • Reducing rear-end and sideswipe crashes. • Improving speed limit compliance, thereby decreasing crash severity when crashes do occur. Such benefits result in reduced vehicle speeds, improved mobility and access, reduced collisions and injuries, and improved livability and quality of life. When modified from four travel lanes to two travel lanes with a two-way left-turn lane, roadways have experienced a reduction in all roadway crashes. The benefits to pedestrians include reduced crossing distance and fewer mid-block crossing locations, which account for most pedestrian fatalities.
Auxiliary lanes—maintenance of homogeneous traffic stream	• Climbing lanes are an auxiliary lane typically used on highways in rural areas. The lanes provide the opportunity for slower vehicles such as large trucks or recreational vehicles to ascend a steep grade outside of the primary traffic stream. As trucks and recreational vehicles must use a low gear to descend a steep grade safely, an additional lane may also be built on the downhill side for that same purpose. • Passing lanes are usually provided at certain locations along rural two-lane highways for the purpose of allowing fast-moving vehicles to safety pass slow-moving vehicles. The need or desire to pass may be prompted by an alignment that prevents use of the opposite travel lane for passing or a steep grade that causes heavy vehicles to slow down. • Runaway truck ramps are designed as an escape route for heavy vehicles that have lost brake functionality on steep downgrades. They are typically constructed on mountainous roads but may occur in urban areas. The ramp is constructed on the right side of the roadway with a bed of gravel or sand up a steep incline. The effects of gravity and the additional friction from the native material safely stop the heavy vehicle.	Adding a lane on the downside hill prevents vehicles from overusing their brakes, which may overheat and cause a runaway vehicle. • Provisions for separating slow-moving vehicles from the traffic stream reduce turbulence and promote more homogeneous operating speeds, which can reduce the potential for crashes. • Providing an escape route for runaway vehicles removes them from the traffic stream, thereby preventing collisions with other vehicles. The potential for an out-of-control heavy vehicle to run off the road or overturn on a curve is minimized with a runaway ramp.

Table A-2. Substantive Safety Considerations: Other Key Elements *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Conflict reduction—turn lanes	The combination of through and turning vehicles introduces conflict into the traffic stream. Vehicles that slow down or stop to wait for a gap in oncoming traffic are not operating in the same manner as through traffic. If those different operating movements occur in the same lane, the traffic stream is no longer operating homogeneously, and conflict is introduced. The provision of a taper to a turn lane allows drivers to decelerate gradually outside a through lane. A dedicated turn lane provides a protected area for drivers to wait until the turn can be completed. Offsetting opposing left-turn lanes improves driver visibility of the oncoming traffic stream and aids in better decision making when judging appropriate turning gaps.	Turn lanes reduce the conflict between turning vehicles and through traffic, which enhances the safety and efficiency of roadway intersections. Research has proved that turn lanes reduce crashes. For example, the installation of a single left-turn lane on a major road approach would be expected to reduce total intersection crashes on three-leg and four-leg intersections in both urban and rural areas.
Automated speed enforcement to promote speed limit compliance	Research suggests that speeding is a factor in roughly 30 percent of traffic fatalities. Most speeding-related crashes occur on non-Interstate roads. Speed limit compliance reduces conflict potential, because drivers operate vehicles at similar speeds, and a more homogeneous traffic stream results. Minor roads, like neighborhood collectors and local streets, serve to provide access. Minor roads must operate at slower speeds because of the increased number of conflict points. Nearly 30 percent of the fatalities that occurred on non-Interstate roads were on low-speed roadways.	A recent study in Korea found that the presence of automated speed enforcement devices reduced crashes and fatalities. According to national studies where automated speed technology has been used, the devices have been effective in reducing travel speeds and improving safety. In most cases, the studies found that automated speed enforcement had a positive effect on reducing speeding.
Median width—design	The most important objective for providing medians is separation of opposite directions of traffic. Design parameters and roadway context typically influence the decision to include a median and the type and width of medians. The substantive safety performance of a roadway can be influenced by differences in those parameters.	• Where cross-median crashes occur, wider medians or median barriers may reduce the frequency of crashes. • A rigid median barrier is a fixed object that will likely be hit by vehicles resulting in an increased frequency of crashes. Single-vehicle and fixed-object crash types tend to be less severe than cross-median crashes. • Providing a median where there was none can reduce crashes.
Median type and access	Selection of median type should be appropriate for the adjacent land use while also considering safety implications. At-grade traversable medians that are flush with the travel lanes are usually delineated with pavement markings. Raised medians can be paved or landscaped. Depressed medians are typically native material, but can be a hard surface such as concrete.	• For rural two-lane roadways, two-way left-turn lanes reduce potential conflicts with turning traffic and provide a refuge from through vehicles for drivers waiting to turn left. • Raised or depressed medians reduce the potential for lane-departure crash types between vehicles traveling in opposite directions. • At-grade medians can provide recovery time for errant vehicles, reducing crashes between vehicles traveling in opposite directions.

Table A-2. Substantive Safety Considerations: Other Key Elements *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Roadside—clear zone	Designers should exercise judgment in selecting an appropriate clear zone, taking into account the location (urban vs. rural), the type of construction (new construction, reconstruction, 3R [resurfacing, restoration, rehabilitation]), and the context.	An adequate clear zone provides the driver with a clear recovery area, free of rigid obstacles and steep slopes, which allows vehicles that have run off the road to safely recover or come to a stop. An adequate clear zone both reduces frequency of crashes with fixed objects on the side of the road and reduces the severity of crashes that do happen.
Intersections, Traffic Control, and Access Management		
Traffic signal control vs. roundaboutsa	Roundabouts have demonstrated substantial safety and operational benefits compared with most other intersection configurations and types of control. Roundabouts can be an effective tool for managing speed and for creating a transition area that moves traffic from a high-speed to a low-speed environment. Proper site selection, channelization, and design features are essential for making roundabouts accessible to all users. Roundabouts can reduce crash severity by converting angle collisions to sideswipe collisions. Also, the potential for head-on crashes is significantly reduced because roundabout designs do not provide opposite-direction travel in adjacent lanes. The splitter islands that provide refuge areas for pedestrians and bicyclists reduce crossing distance and minimize exposure for those users to oncoming traffic.	The *Highway Safety Manual* (HSM) indicates that installation of a roundabout can produce especially significant reductions in fatal and injury crashes: • By converting from a two-way stop control or a signalized intersection to a roundabout, a location can have a reduction in severe (injury/fatal) crashes and in overall crashes. • Information on the effect of roundabouts on pedestrians and bicyclists is limited; however, some trends suggest that they appear to increase safety for those users. Requirements to serve those users are available for incorporation into roundabout design. The benefits have been shown to occur in urban and rural areas under a wide range of traffic conditions. Although the safety performance of all-way stop control is comparable to roundabouts (per the HSM), roundabouts can provide operational advantages.
Two-way vs. all-way stop-controlled intersections	• Not all intersections are candidates for all-way stop control. The decision to create an all-way stop-controlled intersection should consider traffic volumes and patterns, crash history, and a potentially adverse reaction by the driving population. Stop control on the major road could lead to unnecessary delays and could increase the potential for crashes if driver frustration results in noncompliance with the stop signs. • All-way stop control is suitable at intersections with moderate and relatively balanced volume levels on the intersection approaches. • All-way stop-controlled intersections should operate efficiently without substantially more delay than a signalized intersection. • All-way stop control can reduce right-angle and turning collisions at unsignalized intersections by providing more orderly movement, reducing through and turning speeds, and minimizing the safety effect of any sight distance restrictions that may be present.	Various research studies show the reduction in the following types of crashes realized by converting a two-way stop-controlled intersection to all-way stop control: • Total intersection crashes • Overall crashes at urban locations • Left-turn crashes • Right-angle crashes • Rear-end crashes • Pedestrian crashes
Four-leg intersections with minor road stop control vs. offset three-leg stop control	The single minor-street approach is controlled by a stop sign at a three-leg intersection. The minor-street approach can be public streets or private driveways. Converting a four-leg intersection with stop control for the minor-street approaches into two three-leg intersections has the effect of reducing the crossing distance and gap required for the minor-street traffic and reducing the number of conflict points. The minor-street volumes, adjacent land uses, and travel patterns should be carefully considered before implementing this type of conversion.	• In a 1976 study by Hanna et al., offset intersections had crash rates that were lower than the crash rates at comparable four-leg intersections. Thus, it is expected that this strategy would reduce the crash frequency of targeted four-leg intersections. • The HSM suggests that the effect on crash frequency from this conversion depends on the proportion of minor-street volume through the intersection.

Table A-2. Substantive Safety Considerations: Other Key Elements *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Traffic signal timing/phasing	The following timing and phasing improvements to the signal cycle can reduce the potential for angle crashes between left-turning and opposing through vehicles and for rear-end and sideswipe crashes between left-turning vehicles and same-direction through vehicles: • Improve signal timing. • Modify left-turn phase. • Provide actuated control. • Modify change and clearance interval.	A properly timed, protected left-turn phase can help reduce the frequency and severity of crashes. Left turns are widely recognized as the highest-risk movements at signalized intersections. Protected left-turn phases significantly improve the safety for left-turn maneuvers by removing conflicts with the opposing through movement. Split phasing, which provides individual phases for opposing approaches, could improve safety, but it increases the overall delay and should be used cautiously. The overall length of the turn lane is a key element in lane design. A lane that does not provide enough deceleration length and storage space for left-turning traffic could cause the turn queue to back up into the adjacent through lane. That effect can contribute to rear-end and sideswipe crashes and can increase delay for through vehicles.
Traffic signal visibility	Backplates with retroreflective borders should be part of efforts to systemically improve safety performance at signalized intersections. Wherever possible, signal lenses should be upsized. Larger signal heads provide better visibility.	According to a study included in the CMF Clearinghouse, the use of backplates with retroreflective borders may result in a reduction in all crashes at urban, signalized intersections. Installation of larger signal lenses may result in a reduction in urban area angle crashes.
Turn movement permissions/ restrictions	Turn movement restrictions, such as protected left-turn phasing, or eliminations, such as right turns on red, can address issues at locations with high frequencies of crashes related to turning maneuvers.	For right turns on red, the target of this strategy is right-turning vehicles that are involved in rear-end or angle crashes with cross-street vehicles approaching from the left or vehicles turning left from the opposing approach, and crashes involving pedestrians. The HSM indicates that the provision of right-turn-on-red operations increases crash potential for pedestrians and bicyclists.
Automated red-light-running enforcement	Red-light-running cameras are typically an effective deterrent when placed at intersections or along roadways, usually at sites identified as having a high incidence of red-light-running and associated crashes.	Red-light-running cameras in urban areas have reduced the incidence of right-angle and left-turn crashes of all severity types. However, the cameras increase the occurrence of rear-end crashes because of varying levels of respect for them shown by drivers.
Intersection stop control vs. signal control	Traffic signals assign right-of-way to conflicting movements, which helps reduce conflict points. Left-turn phases can reduce the frequency of angle crashes, which tend to be severe, especially on high-speed roads. Signals provide designated crossing times for pedestrians and bicyclists.	The installation of a traffic signal will normally reduce angle crashes in both rural and urban areas. Rear-end crashes can be expected to increase. Rear-end crashes tend to be less severe than angle crashes.
Alternative intersection designs	Alternative intersection designs, such as split intersection (with possible median U-turn), displaced left-turn, median U-turn, restricted crossing U-turn, and quadrant roadway intersections, may offer additional benefits compared with conventional at-grade intersections.	The common factor among these types is the removal of one or more conflicting traffic maneuvers from the major intersection, thereby reducing the required number of signal phases. The safety benefit is realized in reduced conflict points and provision for smoother operating conditions through shorter signal lengths, less delay, and higher capacity.
Alternative interchange designs	Alternative interchange designs, such as double crossover and displaced left-turn interchanges, may offer additional benefits compared with conventional grade-separated diamond interchanges.	The common factor between the interchange treatments is the elimination of the conflict between left turns and opposing through movements. The safety benefit is realized in fewer conflict points and the provision of smoother operating conditions through shorter signal lengths, less delay, and higher capacity.
Skew angle of intersections	A skewed intersection results when the two roadways intersect at an angle of less than 90 degrees. The resulting geometry can influence both the safety and operational characteristics of an intersection by reducing sight distance (which increases right-angle-type crashes) and increasing crossing distances for pedestrians and vehicles. Those effects are more pronounced for stop-controlled intersections than signalized intersections.	Reducing the skew improves sight distance, which could enable drivers to better judge gaps in oncoming traffic. Reducing the skew reduces crossing distances, which limits the exposure of pedestrians and bicyclists to oncoming traffic.

Table A-2. Substantive Safety Considerations: Other Key Elements *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Turn lanes	Turn lanes are a treatment that can be included in a complete reconstruction of the intersection or can be added to an existing intersection to improve the safety and efficiency of the intersection.	There are many crash modification factors (CMFs) for left- and right-turn lanes with various results. In general, the trends are positive and result in reduced crashes. The addition of left-turn lanes results in a reduction in rear-end and sideswipe crashes and a smaller reduction in all crashes. The addition of right-turn lanes results in a reduction of all crash types.
Intersection lighting	Improving intersection visibility by installing lighting can warn drivers of the upcoming intersection and potential for conflicts with vehicles, pedestrians, or bicyclists. An analysis that includes the following data should be conducted to determine if lighting is warranted for a particular location: • Traffic volumes • Spacing of freeway interchanges • Lighting in adjacent areas • Night-to-day crash ratio	Studies have shown a reduction in nighttime fatal crashes with the use of roadway lighting. Minnesota conducted a literature review and found that published research reported reductions in the nighttime-crash to total-crash ratio from the installation of intersection lighting.
Flashing beacons	• Overhead flashing beacons are intended to heighten driver awareness of the potential for upcoming conflicts with vehicles or pedestrians and bicyclists. At stop-controlled intersections, flashing beacons are intended to reinforce driver awareness of the stop sign and to help mitigate patterns of right-angle crashes related to stop sign violations. • Rectangular rapid-flashing beacons are user-actuated amber LEDs that supplement warning signs at unsignalized intersections or mid-block crosswalks. They can be activated by pedestrians manually by a pushbutton or passively by a pedestrian detection system. They can be installed on two-lane or multilane roadways.	Ohio found that flashing beacons generally reduced vehicular speeds on major roads, particularly at intersections with sight distance restrictions, but they were not necessarily effective in reducing stop sign violations or crashes. The use of rectangular rapid-flashing beacons to increase driver awareness of potential pedestrian conflicts has the potential to enhance safety by reducing crashes between vehicles and pedestrians at unsignalized intersections and mid-block pedestrian crossings.
Pavement markings for driver guidance	Delineations such as pavement markings have long been considered an essential element for providing guidance to drivers. Pavement markings alert drivers to an upcoming change in condition, so they are prepared to react if a potential conflict arises. Redundancy with pavement markings helps the driver process information accurately and quickly.	Pavement markings provide information on the road surface where drivers focus their attention. However, they may be difficult to see at night in wet or snowy conditions.
Access management for driveways and corner clearance	Driveways within the functional area of an intersection introduce turbulence in the traffic stream. Confusion can exist about whether brake lights or turn signals apply to a driveway or to the upcoming crossroad. Similarly, the potential for rear-end crashes increases if a following driver does not expect a lead driver to slow down sooner for a driveway rather than later for the upcoming crossroad.	Although no specific measure is available to quantify the effects of driveways within the functional area of the intersection, it is generally accepted that eliminating and/or reducing the number of access points within the functional area of an intersection reduces the potential for crashes, because the operating characteristics of the traffic stream are more homogeneous.

Table A-2. Substantive Safety Considerations: Other Key Elements *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Access management for intersection frequency	Every at-grade intersection, from a busy signalized intersection to a simple unpaved driveway, has the potential for conflict among motorized vehicles, pedestrians, and bicyclists. The number and types of conflict points (number of locations where the travel paths of two different users may cross) influence the safety performance of the intersection or driveway. Access management techniques can manage the frequency and magnitude of conflict points at intersections and driveways by altering access patterns. The following are common access management treatments: • Driveway closure, consolidation, or relocation • Restricted-movement designs for driveways (such as right-in/right-out only) • Restricted-movement and alternative designs for intersections (such as J-turns, median U-turns, and quadrant roadways) • Raised medians that prevent cross-roadway movements and that focus turns and U-turns on key intersections • Auxiliary turn lanes (including exclusive left or right and two-way left) • Parallel, lower speed one- or two-way frontage roads for access • Roundabouts or mini-roundabouts to provide needed or desired access	A corridor access management approach involves seeking an appropriate balance between the safety and mobility of a roadway facility with the access needs of adjacent land uses. According to the HSM, areas where effective access management has been implemented have experienced a reduction in all crashes along two-lane rural highways and a reduction in severe (injury/fatal) crashes along urban and suburban arterials.
Access control	Access management programs seek to limit and consolidate access along major roadways, while promoting a supporting street system and unified access and circulation systems for development. • Provide a specialized roadway system: Different types of roadways serve different functions. It is important to design and manage roadways according to the primary functions that they are expected to serve. • Provide a supporting street and circulation system: Well-planned communities provide a supporting network of local and collector streets to accommodate development, as well as unified property access and circulation systems. Major roads should be allowed to function as intended: Major roads are meant to carry higher volumes of through traffic at higher speeds that are relatively consistent among the vehicles in the traffic stream. Restricting roadside access and permitting gradual vehicle acceleration through use of special lanes or ramps on freeways and higher-speed arterials maintain a more homogeneous operating speed in the traffic stream. The main function of major roads, like Interstate freeways and regional highways, is to move traffic over long distances at higher speeds. Access to such roads must be carefully managed, so requests for new access to development do not contribute to congested conditions that could adversely affect safety.	• Interconnected street and circulation systems support alternative modes of transportation and provide alternative routes for bicyclists, pedestrians, and drivers. Alternatively, commercial strip development with separate driveways for each business forces even short trips onto arterial roadways, thereby reducing safety and impeding mobility. • Frontage or service roads provide lower-speed access to commercial sites along a major roadway and to separate business traffic from higher-speed through traffic. Connections of frontage or service roads to side streets or onto the highway must be located an appropriate distance from signalized intersections so that entering and exiting traffic does not conflict with traffic queuing at signals. A lesser speed differential can reduce the frequency and severity of crashes between through vehicles and entering and exiting vehicles.
Access management for driveway frequency	Major roadways that serve higher volumes of regional through traffic need more access control to preserve their traffic function. Frequent and direct property access is more compatible with the function of local and collector roadways.	• Driveway access to a major roadway results in a mix of vehicle operating speeds between entering and exiting vehicles and mainline through traffic. The incidence of that speed differential at multiple points causes turbulence in the traffic stream that can increase the frequency of crashes. • Fixed objects, such as signs associated with driveway access points, can increase the potential for roadside fixed-object crashes.

Table A-2. Substantive Safety Considerations: Other Key Elements *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Special-purpose lanes for bus/ HOVs	Presence/location of bus stops • High-occupancy vehicle (HOV) lanes are normally implemented to increase average vehicle occupancy and person throughput with the goal of reducing traffic congestion and air pollution. • Bus lanes give priority to buses and cut down on journey times where roads are congested with other traffic.	The traffic speed differential between HOV and general-purpose lanes creates a potentially dangerous situation if the HOV lanes are not separated by a barrier. A Texas Transportation Institute study found that HOV lanes lacking barrier separations caused an increase in injury crashes. Streets with shared bus lanes appear to reduce total crashes.
Roadway Networks		
Directional flow/ one-way or two-way street operation	One-way operation for streets is considered for various operational and safety reasons: • Provide easier traffic flow because the street is too narrow for movement in both directions. • Prevent drivers from cutting through residential streets (rat runs) so as to bypass traffic signals or other requirements to stop. • Create a one-way pair out of two parallel one-way streets in opposite directions (a divided highway). • Provide proper functioning system of paid parking or other paid access. • Eliminate the need for a center turn lane that could be used for through travel. • Improve traffic flow in densely built-up areas where road widening may not be feasible. • Reduce conflict points between vehicles traveling in different directions.	One-way operation has the following positive effect on safety: • Reduced congestion and increased traffic flow, which reduce the potential for rear-end and same-direction sideswipe crashes. • Reduced conflicts at access points where turning maneuvers occur. • Reduced exposure to oncoming traffic for pedestrians and bicyclists. Possible negative effects are: • Increased speeds in urban areas. • Increased circulating traffic to reach their destination or looking for parking.
Environmental conditions/ weather and maintenance	Weather affects driver capabilities, vehicle performance, pavement friction, roadway infrastructure, crash risk, traffic flow, and agency productivity. According to research conducted by the FHWA and Transportation Research Board, a significant proportion of wet pavement crashes occur on surfaces with inadequate pavement friction. Wet pavement crashes could be prevented or minimized by improving pavement friction. During wet weather conditions, conventional static speed limit signs may not display an appropriate, reasonable, and/or safe speed limit for those conditions. The use of variable speed limit (VSL) systems during inclement weather or other less-than-ideal conditions can improve safety by decreasing the risks associated with traveling at typical operating speeds.	Pavement resurfacing can improve skid resistance in locations where a high percentage of crashes occur on wet pavements or curves in the roadway.

Table A-2. Substantive Safety Considerations: Other Key Elements *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Angle vs. parallel parking	Advantages and disadvantages of angle and parallel parking include the following: *Parallel parking* • Roads that facilitate parallel parking have an extra lane or a large shoulder for parked cars. Parallel parking is used where parking facilities are not available, usually in large metropolitan areas with a high density of vehicles and few (or restricted) accommodations, such as multistory parking garages. • Many jurisdictions restrict parallel parking during rush hour to provide increased capacity for through movements and to reduce conflicts between through and parking movements. *Angle parking* • Angle parking is very common in parking lots. • It may be used for street-side car parking if more width is available for car parking than would be needed for parallel parking of cars. • It can be mostly used in residential, retail, and mixed-use areas where additional parking—compared with parallel parking—is desired, and traffic volumes are lower. Adequate sight distance for drivers at stop-controlled approaches to intersections has long been recognized as among the most important factors contributing to overall intersection safety. Although geometrically an intersection might have adequate sight distance, parking within the sight triangle might impede the sight distance.	Cycling organizations consider angle parking undesirable compared with parallel parking for the following reasons: • There is a significant risk to cyclists from vehicles reversing out, as approaching bicyclists are in the blind spot of reversing and turning vehicles. • Longer vehicles project farther into the road, which can inconvenience or endanger other road users. • The "surplus" road space that enables angle parking could be used for bicycle lanes. Currently, no research adequately quantifies the effectiveness of improving sight distance at unsignalized intersections because of the elimination of parking. However, the known benefit of improving sight distance at intersections indicates that removal of parking where it could potentially obstruct sight distance would have a positive effect on safety and would thereby result in a decrease in crashes. Rear-in angle parking reduces crashes, creates a safer environment for cyclists, car doors herd children back to the curb instead of out into the street, and cars trunk loading is at the curb.
Special Conditions: Pedestrian and Bicycle Facilities		
Presence of sidewalks	All roadways along which pedestrians are not prohibited should include an area where pedestrians can safely walk, on sidewalks in urban areas and on shoulders in rural or less developed areas.	Design features of the sidewalk should allow pedestrians to have a sense of security and predictability. Sidewalk users should not feel they are at risk from adjacent traffic. Most highway shoulders are not pedestrian facilities, because they are not intended for use by pedestrians, although they can accommodate occasional pedestrian usage.
Median/pedestrian crossing islands	Raised medians (or refuge areas) should be considered in curbed sections of multilane roadways in urban and suburban areas, particularly in areas with mixtures of significant pedestrian and vehicle traffic (more than 12,000 average daily traffic) and intermediate or high travel speeds. Medians or refuge islands should be at least 4 feet wide (preferably 8 feet to accommodate pedestrian comfort and safety) and of adequate length to allow the anticipated number of pedestrians to stand and wait for gaps in traffic before crossing the second half of the street.	There are several types of medians and pedestrian crossing islands. If designed and applied appropriately, they improve the safety benefits to both pedestrians and vehicles in the following ways: • They may reduce pedestrian crashes as well as motor vehicle crashes. • They give pedestrians a safe place to stop at the midpoint of the roadway before crossing the remaining distance. • They enhance the visibility of pedestrian crossings, particularly at unsignalized crossing points. • They can reduce the speed of vehicles approaching pedestrian crossings. • They can be used for access management for vehicles (allowing only right-in or right-out turning movements). • They provide space for supplemental signage on multilane roadways. • Raised medians or pedestrian refuge areas at both marked and unmarked crosswalks have shown a reduction in pedestrian crashes.

Table A-2. Substantive Safety Considerations: Other Key Elements *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Mid-block crosswalks	A driver may not expect to encounter a pedestrian crossing the street between intersections. Safety-related features should be considered to enhance driver expectancy in such situations. The following treatments can be used to improve pedestrian safety at mid-block crosswalks or crossings of uncontrolled intersection approaches: • Angled median cut-through • Ladder or a cross-hatched crosswalk pattern • Advance yield markings farther back from crosswalk • Raised crosswalks • Curb extensions • Lane reductions/road diets to reduce roadway width • "Pedestrian Crossing" warning signs • In-pavement lights • "Stop for Pedestrians" (R1-6) or "Yield to Pedestrians" signs • Rectangular rapid flash beacons (RRFB)	Where an unsignalized crossing exists, enhanced crossing treatments such as the following increase visibility of the pedestrian: • Median cut-throughs are angled to encourage pedestrians to look at oncoming traffic. • A ladder or cross-hatched pattern is more visible to motorists. • "Pedestrian Crossing" warning signs with pedestrian-actuated flashing beacons or rapid rectangular flashing beacons alert oncoming traffic to pedestrians in the crosswalk. • "Stop for Pedestrians" (R1-6) or "Yield to Pedestrians" signs placed at crosswalks without signals reinforce and remind drivers of the laws regarding yielding the right-of-way to pedestrians. • Stop lines at mid-block crossings set back at 20 to 50 feet ensure that persons the crossing street are visible to a second driver when the first driver is stopped at stop line. • Raised crosswalks may pose hazards to motorcyclists and bicyclists if not clearly visible through the use of signs and pavement markings.
Bicycle facilities at interchange ramp intersections	Bicycle lanes through interchanges should be designed such that bicyclists cross at right angles to ramps.	This configuration increases driver sight distance and reduces the potential for bicycle crashes.
Traffic control for pedestrian facilities	Traffic control devices should be considered to improve driver expectancy for pedestrians crossing the roadway. They include pavement markings and warning signs. Traffic signal enhancements that can benefit pedestrians and bicyclists are also widely used. • Pedestrian hybrid beacons (also known as High-intensity Activated crossWalK, or HAWK, beacon) should be used if gaps in traffic are not adequate to permit pedestrians to cross, if vehicle speeds on the major street are too high to permit pedestrians to cross, or if pedestrian delay is excessive. Beacons should be used only in conjunction with a marked crosswalk. • Traffic signal enhancements include automatic pedestrian detectors, providing larger traffic signals to ensure visibility, placing signals so that motorists waiting at a red light cannot see the other signals and anticipate the green, and installing countdown signals to inform pedestrians of the amount of time remaining in a crossing interval. • Pedestrian phases can be included in the signal timing to guide pedestrians about the appropriate time to enter the crosswalk. According to the MUTCD, pedestrian signal indications should be used at traffic signals wherever warranted.	Pedestrian-activated beacons, warning signs, and advance pavement markings all benefit safety. HAWK installations have been shown to reduce total roadway crashes and pedestrian crashes in particular. CMF Clearinghouse (search "HAWK"), http://www.cmfclearinghouse.org/.
Lane/roadway modifications to accommodate bicycle facilities	Several methods are available to provide bicycle facilities. Separating bicyclists from vehicular traffic can improve safety by reducing the potential for conflict between those two travel modes. The following are examples of ways to create bicycle facilities: • Widening curb lanes • Widening or restriping roads to create dedicated bicycle lanes • Designating shared bus/bicycle lanes • Paving shoulders • Constructing exclusive bicycle facilities	Trend information, generally applicable to urban and suburban areas only, indicates that those types of facilities reduce crashes involving bicycles and vehicles.

Table A-2. Substantive Safety Considerations: Other Key Elements *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Channelization for pedestrians and bicyclists	Intersection channelization can provide refuge or reduce the exposure distance for pedestrians and bicyclists within an intersection without limiting vehicle movement. Practitioners should consider using raised medians, traffic islands, and other pedestrian-friendly treatments in the design.	Channelization can limit frequency or reduce the severity of crashes in several ways: • Discourage undesirable movements. • Define desirable paths for vehicles. Avoiding undesirable effects can improve both safety and capacity at an intersection. • Encourage safe speeds through design. • Separate points of conflict where possible. • Facilitate the movement of high-priority traffic flows. • Design approaches to intersect at near right angles and merge at flat angles. • Facilitate the desired scheme of traffic control. • Accommodate decelerating, slow, or stopped vehicles outside higher-speed through traffic lanes. • Provide safe refuge and wayfinding for bicyclists and pedestrians.
Traffic calming	Traffic calming can promote slower vehicular travel speeds, which reduce the potential for crashes with vehicles and can reduce the severity of a crash that occurs. • One method to calm drivers and to slow speeds is to implement a speed hump, which is typically installed on residential roads in urban or suburban environments with the intent to reduce speeds and, in some cases, reduce traffic volumes. • Transverse rumble strips serve a similar purpose to slow drivers. • Curb extensions and bulb-outs give the appearance of a narrow road, which tends to encourage drivers to travel at slower speeds.	If the traffic-calming devices successfully encourage drivers to slow down, they could improve safety for pedestrians and bicyclists. Speed humps may pose hazards to motorcyclists and bicyclists if not clearly indicated by the use of signs and pavement markings. Traffic calming may divert traffic to other non-calmed streets.
Walkability/ bikeability (including ADA/ accessibility)	Substantive safety can be incorporated into livability goals that focus on the provision of adequate sidewalks and bicycle facilities. Walkability in a community is enhanced when sidewalk gaps are closed—particularly around schools and transit centers—to encourage walking as a safe, feasible transportation mode. Sidewalks are important to walkability. The Americans with Disabilities Act requires that sidewalks be at least 5 feet wide. Multiuse paths that accommodate both pedestrians and bicyclists should be even wider to safely and efficiently accommodate both travel modes.	A continuous sidewalk and path network reduces the likelihood that pedestrians and bicyclists will travel in the roadway, thereby decreasing the potential for crashes, particularly in low-light conditions.
Special Conditions: Work Zones and Maintenance of Traffic		
Lane merge systems	Lane merge systems are dynamic traffic control systems that encourage drivers to switch lanes in advance of work zone lane drop and entry taper. • Changeable speed warning signs • Changeable message signs	This strategy provides potential to reduce the number of merging conflicts and to reduce vehicle delay.
Work zone length/ duration	Maintenance of traffic plans should strive to minimize both length of work zone and the duration of time that the work zone is maintained	Limiting work zone length and duration reduces exposure of both motorists and workers to risk of injury and/or crashes.
Daytime vs. nighttime work	Nighttime construction offers a potential operational benefit when compared with daytime operations where high volumes and congestion exist. When nighttime construction is conducted, work zone illumination appears to affect the safety of a work zone.	Compared with the non-work-zone condition, crashes appear to increase more at work zones during the night than during the day. However, there is limited research comparing daytime to nighttime crash performance on the same project or highway section. High visibility of work vehicles at intersections, especially at night, may reduce the risk of crashes. At intersections, properly aimed and adjusted work lights can provide good illumination without causing glare issues.

Table A-2. Substantive Safety Considerations: Other Key Elements *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Maintenance of bidirectional traffic in work zones	Two main types of lane closure designs exist for work zones on freeways, rural multilane roadways, and urban and suburban arterials: • Roadway closure with two-lane, two-way operation • Single (partial)-lane closure	Research is inconclusive on the relative difference between maintaining two-way and single-lane closures other than to find that both conditions result in more crashes than the non-work-zone condition. Some evidence indicates that there may be a greater chance of a higher-severity crash in a roadway closure with a two-lane, two-way traffic operation section than in a partial closure. However, the magnitude of the potential crash effects is not well defined.
Temporary pavement markings	Pavement markings to provide guidance to drivers are important for safety on all roadways. It is especially important where the lanes vary from the permanent lanes, cross the pavement, or do not line up with joints in the pavement. It is important to remove pavement markings that conflict with those of the current stage.	Increased information on the proper route through the work zone reduces lane-departure crashes.
Channelizing devices	Raised reflective pavement markers, reflectors on temporary barriers, or delineators can provide guidance during conditions where it is difficult to see the pavement markings.	Increased information on the proper route through the work zone reduces lane-departure crashes. Delineation is likely to have an added effect in work zones where conditions may be unfamiliar or may have changed substantially from the non-work-zone condition.
Work zone barriers and end treatments	Barriers provide guidance to motorists and protection by separating the traffic from the work area.	Barriers will prevent vehicles from entering the work area where a crash could occur with workers or construction equipment. Paddles or glare screens can be placed on barriers to reduce the distraction to drivers from the work taking place.
Maintenance of Traffic/diversions and detours	It is more efficient for the construction work to close the road and to allow the contractor access to the entire site. Closure requires a detour route for the traveling public. Even when the road is not closed, the capacity will usually be less when the work zone is set up.	Providing an alternate route to divert some traffic will help reduce the volume of traffic and delay through the work zone. Reducing the level of congestion helps reduce rear-end crashes in the work zone.
Portable changeable message signs	Changeable message signs can help provide up-to-date information to motorists.	Informing drivers of an incident or warning them of any condition ahead that requires action on their part helps reduce follow-on crashes.
Emergency response provisions	When shoulders cannot be provided through a long work zone, pulloff areas should be provided. Access-controlled routes may need a temporary emergency access to allow emergency responders to get to crashes or incidents.	Pulloff areas allow motorists to pull disabled vehicles out of the primary traffic flow, reducing disruption to traffic and risk of crashes as well as providing areas for emergency services and enforcement activities.
Special Conditions: Work Zones and Maintenance of Traffic		
Speed management/ variable speed limits	VSLs change speed limits dynamically as a function of traffic. VSLs are used to encourage drivers to proceed slowly in certain areas or when driving conditions deteriorate, through the use of changeable message signs or other devices. Roadways with conditions that may vary are potential locations for VSLs. VSLs are most commonly used on highways with one or more of the following characteristics: • Traffic congestion • Incidents/crashes • Inclement weather (snow, ice, fog) • Smoke/fog from industrial activity • Construction zones • School zones	CMFs from the FHWA Clearinghouse are available for side-mounted VSLs (no information is available for VSLs mounted above lanes) and are indicated for potential crash reduction.
Dynamic messaging systems	Dynamic messaging systems are used to inform travelers about special events. Such signs warn of traffic congestion, crashes, incidents, roadwork zones, or speed limits on a specific highway segment. In urban areas, they are used within parking guidance and information systems to guide drivers to available car parking spaces. They may also ask motorists to take alternative routes and to limit travel speed, may warn of duration and location of incidents, or may just inform motorists about traffic conditions.	Dynamic messaging systems can improve motorists' route selection, reduce travel time, mitigate the severity and duration of incidents, and improve the performance of the transportation network. The HSM has a CMF reporting an expected reduction for injury rear-end crashes and an increase for property-damage-only rear-end crashes on freeway facilities for this countermeasure and treatment.

Table A-2. Substantive Safety Considerations: Other Key Elements *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Speed harmonization and dynamic lane management	Speed, demand, and available capacity can be proactively managed on the facility by applying new strategies or modifying existing strategies. This approach makes the most effective and efficient use of a freeway facility and decreases congestion. The balance of traffic flow across lanes results in less variability in speed and flow between vehicles traveling in the same traffic stream.	This strategy reduces the risk of conflict between vehicles of differing speed and decreases the risk of crashes and crash frequency. Limited research exists for application of this strategy in the United States, but European studies documented in research performed for the FHWA indicate that implementation of this strategy can result in a reduction in crashes. (See FHWA, *Active Traffic Management: The Next Step in Congestion Management.*)
Traffic management centers—incident response	The following steps should be taken for incident response management: • Assist in incident detection and verification. • Initiate traffic management strategies on incident-affected facilities. • Protect the incident scene. • Initiate emergency medical assistance until help arrives. • Provide traffic control. • Assist motorist with disabled vehicles. • Provide motorist information. • Provide sand for absorbing small fuel and antifreeze spills. • Provide special equipment to clear incident scenes. • Determine incident clearance and roadway repair needs. • Establish and operate alternate routes. • Coordinate clearance and repair resources. • Serve as incident commander for clearance and repair functions. • Repair transportation infrastructure.	Effective traffic incident management reduces the duration and effects of traffic incidents and improves the safety of motorists, crash victims, and emergency responders.
Freeways/Interchanges		
Interchange spacing	AASHTO suggests interchange spacing of at least 1 mile in urban areas and 2 miles in rural areas.	Trends identified in the HSM suggest that decreasing the spacing between interchanges tends to increase crashes.
Ramp type/ configuration	The following components of freeway and interchange designs may affect the safety performance of those types of facilities: • Design speed • Horizontal geometrics • Cross section • Ramp terminal design	A trend identified in the HSM suggests that wider off-ramp lanes decrease crash frequency. Safety prediction models can be used to estimate the crash frequency associated with various configurations.

Table A-2. Substantive Safety Considerations: Other Key Elements *(continued)*

Design Element	Substantive Safety Principles	Typical Safety Effects
Left-side exit/ entrance ramps	Although driver expectancy is for entrance and exit maneuvers to occur on the right side of a freeway or interchange, circumstances such as the following may suggest the need to consider left-side ramps: • A demand for a high-volume directional movement. • Economic considerations, mainly structural movement. • Right-of-way and natural barriers, such as a river or a lake requiring special geometric treatment. • The elimination of weaving. • Lack of left-turn storage at diamond interchanges. • A need to provide higher capacity at the cross street by arranging for left-turning movements that do not cross each other. • A need to provide access to service and rest areas in a widened median, as is done on some toll roads. • As part of a sequence of right-hand off-ramps and left-hand on-ramps, a need to provide service to several cross streets in the central area that are too close together to permit access to the streets from one side of the freeway only.	Trend information suggests left-side ramps increase crash frequency and severity. The following could be reasons for this: • Drivers expect right-side exits and entrances, so left-side ramps conflict with expectations. • Drivers planning to exit a freeway may expect the exit to be on the right and thus may be in the wrong lane when approaching a left-side off-ramp. • Slower-moving vehicles may impede faster vehicles in the left lanes as they merge over to a left-side exit ramp.
Crossroad above vs. below	Configurations in which the crossroad is above the main line appear to exhibit better safety performance than interchanges in which the intersecting road crosses below the main line.	The CMF shown in the HSM indicates that a reduction in all crash types in the interchange area can be expected if the crossroad is above the freeway or Interstate.
Collector-distributor road weaving	Collector-distributor roads between interchanges reduce conflicts by relocating weaving maneuvers from the main line to auxiliary roadways where they can occur with lower volumes and operating speeds.	Moving the weaving maneuvers to collector-distributor roads results in more uniformity in the main-line traffic stream, which can reduce the crash frequency and severity associated with weaving areas.
Directional separation barrier	Barrier design and placement need to effectively protect motorists traveling in opposing lanes, while also considering the safety of the occupants in the errant vehicle. Among the factors involved in selection of a barrier system are types of vehicles using the roadway, roadway geometry, and potential severity of a median crossover crash.	Head-on crashes at highway speed are generally more severe than other types of highway crashes. Standard barriers capable of redirecting passenger cars, light vans, and trucks are considered cost-effective for most situations. A higher-performance median barrier may be more appropriate at locations with adverse geometrics, high traffic volumes and speeds, significant amounts of heavy truck traffic, or special environmental considerations.
Ramp metering	Ramp meters use traffic signals to control the vehicular rate of entry from on-ramps to freeway main-line lanes. One or two vehicles merging into the traffic stream at a time have less of an effect on the main-line traffic stream than an entire platoon of vehicles attempting to merge at once. Homogeneous traffic streams tend to reduce the potential for crashes.	The installation of ramp meters may result in a reduction in all types of crashes. Ramp metering may cause congestion on arterials leading to the freeway.
Entrance ramp acceleration	An entrance ramp should provide sufficient length that an entering driver can accelerate to freeway speed and find an adequate gap before merging into main-line traffic. Such a ramp will reduce turbulence in the main-line traffic stream and will reduce the potential for crashes in interchange areas.	Speed differentials between traffic traveling in the same direction increase the risk of crashes. Inadequate gaps can increase the potential for sideswipe crashes.
Changing weave configuration	Converting a two-lane merge/diverge section to one lane has a positive effect on safety. Exiting vehicles must change lanes only once rather than twice while weaving across entering traffic.	The HSM suggests a reduction in all types of crashes in the merging lane.
Auxiliary lane between entrance and exit ramp	Provision of an auxiliary lane allows more room for the entering and exiting maneuvers associated with interchanges. A lane change is required for weaving vehicles. The additional lane lowers the density of vehicles in the freeway segment.	According to the CMF Clearinghouse, installation of an auxiliary lane may result in a reduction in all crashes. Increasing the length of weaving areas between entrance and exit ramps tends to reduce crash frequency.
Exit ramp deceleration	An exit ramp should provide sufficient length that the driver need not decelerate in the main-line through lanes.	Extending the off-ramp deceleration distance has a positive effect on safety. An extension in the deceleration length would tend to reduce crashes.

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