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16. Abstract

Highway safety is an ongoing concern to the Texas Department of Transportation (TxDOT). As part of its proactive commitment to improving highway safety, TxDOT is moving toward including quantitative safety analyses earlier in the project development process. The objectives of this research project are: (1) the development of safety design guidelines and evaluation tools to be used by TxDOT designers, and (2) the production of a plan for the incorporation of these guidelines and tools in the planning and design stages of the project development process.

This document summarizes the research that was conducted and the products that were developed during this six-year research project. It also describes a plan to incorporate safety design guidelines and evaluation tools into the project development process. It is intended for use by engineers responsible for the planning and design of streets and highways.

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DEVELOPMENT OF SAFETY PERFORMANCE MONITORING PROCEDURES

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data published herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) and/or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. It is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was James Bonneson, P.E. #67178.

NOTICE

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. INTRODUCTION

OVERVIEW

There is a growing public demand for safer streets and highways. In response to this demand, state and national transportation agencies have developed safety programs that emphasize public education, accelerated highway renewal, community-sensitive street systems, and innovative technology to facilitate safe highway design.

Historically, information about the safety effect of a design component has been based on anecdotal evidence, laws of physics, before-after studies, or comparisons of site safety (i.e., sites with and without the design component). However, the accuracy of this information is suspect because of the inherent random nature of crash data and the many factors (some of which pertain more to the driver and the vehicle than the roadway) that can lead to a crash at a specific location. As a result of this uncertainty, engineers have traditionally come to rely on design standards and policies to guide them in the design process, with the underlying premise that compliance with warrants and controls will yield a "safe" roadway.

In general, the safety experience with roadways built in compliance with warrants and controls has been good and the aforementioned premise largely validated. However, the weaknesses of this traditional design approach have become more apparent as traffic demands increased over time, the performance of vehicles improved, and drivers became less patient. Points along the roadway having multiple, complex geometric components that tend to concentrate traffic and increase their interaction have started to show disproportionately high crash frequencies. Fortunately, in the past decade, new statistical analysis methods have been developed, and the quality of crash data has improved. These advances have significantly increased both the accuracy and coverage of design-related safety information. Emerging technology is now making it possible to efficiently incorporate quantitative safety evaluations in the design process.

A significant amount of new safety information has been developed in recent years. The implementation of this information is now as pressing a problem as was the need for new research a decade ago. The forthcoming *Highway Safety Manual* is expected to formalize the safety evaluation process; however, the *Highway Safety Manual* procedures will require local calibration to ensure that they accurately reflect the conditions in the jurisdiction for which they are used (*1*). Moreover, it is likely that each agency will want to tailor the calibrated procedures to ensure their consistency with local design policies.

OBJECTIVES

Highway safety concerns are also evident in Texas. Crashes in Texas continue to increase and currently exceed 300,000 per year. Nearly 3800 motorists die annually on Texas highways. As part of its proactive commitment to improving highway safety, the Texas Department of Transportation (TxDOT) is moving toward including quantitative safety analyses throughout the project development process. This research project has the following objectives:

(1) the development of safety design guidelines and evaluation tools to be used by TxDOT designers, and (2) the production of a plan for the incorporation of these guidelines and tools in the planning and design stages of the project development process.

Safety design guidelines and evaluation tools developed in this project (or identified in the literature) were compiled in the *Roadway Safety Design Workbook* (*Workbook*) (*2*). The *Workbook* contains 44 safety prediction models and 70 accident modification factors.

This report has two objectives. The first objective is to summarize the research approach and documents that were developed during this six-year project. The second chapter provides this summary.

The second objective of this report is to document a safety performance monitoring procedure. This procedure incorporates the *Workbook* guidance into all three stages of TxDOT's project development process (*3*). These stages include planning and programming; preliminary design; and plans, specifications, and estimates (PS&E). The procedure is described in the third chapter.

DEFINITIONS

This section defines several terms related to highway safety. The definitions offered are consistent with their use in the safety-related literature; however, they may be refined for consistency with TxDOT design practice and the objectives of this research project.

Accident modification factor (AMF) is a constant or equation that represents the change in safety following a change in the character of a segment (or intersection). An AMF can be computed as the ratio $N_w/N_{w/o}$, where N_w represents the expected number of crashes experienced by a highway segment *with* one or more specified design components, and $N_{w/o}$ represents the expected number of crashes experienced by the same segment *without* the specified components. AMFs are often used as multiplicative factors to adjust the estimate obtained from a safety prediction model to a value that reflects the safety of a specific segment (or intersection).

AMFs typically range in value from 0.5 to 2.0, with a value of 1.0 representing no effect on safety. AMFs less than 1.0 indicate that the specified component is associated with fewer crashes.

To illustrate the concept of AMF, consider a road segment that has an expected crash frequency of 3.0 crashes/yr. A change is made to the road cross section and, after a period of time, a follow-up evaluation indicates that the change resulted in an expected crash frequency of 4.0 crashes/yr. The AMF for this change is 1.3 (= 4.0/3.0).

As a second illustration, consider that a safety prediction model is used to estimate the expected crash frequency of a typical 2-lane highway with a specified average daily traffic volume (ADT) and length. The model was developed to reflect the following as "typical": 12-ft lanes, 6-ft shoulders, no grade, no horizontal curves, 10-ft horizontal clearance, 1V:4H side slope, and no vertical grades. This model estimates an expected crash frequency of

5.0 crashes/yr for the "typical" road segment. It is desired to estimate the crash frequency of a specific road segment for which all geometric elements are "typical" except that the clear zone is 20 ft wide. The AMF for horizontal clearance has a value of 0.93 when the clearance distance is 20 ft. Thus, the expected crash frequency for the specific road segment is estimated as 4.6 crashes/yr (= 5.0 × 0.93).

An *individual* AMF is used to describe the safety influence of a specific geometric attribute (e.g., lane width, shoulder width, or grade). A *combined* AMF is the product of multiple individual AMFs, and is used to describe the combined safety influence of multiple geometric attributes.

Crash reduction factor (CRF) is a constant that represents the proportion of crashes reduced as a result of a safety improvement at a specific location or along a specific road segment. CRFs typically range in value from 0.10 to 0.90. Larger CRFs in this range indicate a more significant reduction in crashes due to the improvement. To illustrate, consider a road segment that has a crash frequency of 3.0 crashes/yr. An improvement is made to the road's cross section and, after a period of time passes, a follow-up evaluation indicates that the change resulted in a crash frequency of 2.0 crashes/yr. The CRF for this improvement is 0.33 (= [3.0 −2.0]/3.0), representing a 33 percent reduction in crashes.

Injury crash is a crash wherein one or more of the persons involved is injured. The injury severity is reported as "possible," "non-incapacitating," or "incapacitating."

Safety (or "substantive safety") is the expected crash frequency associated with a segment (or intersection) for a given set of design components, traffic control devices, and exposure conditions (e.g., traffic volume, segment length). Given that crashes are random events and that conditions can change over time, the safety of a specific segment is best conceptualized as the long-run average of the crash frequencies reported for a large group of segments with similar features and traffic conditions.

Safety evaluation tool is, at its simplest level, a set of equations that can be used to predict: (1) the safety of a given segment (or intersection), and (2) the safety effect associated with a change in its design features. At this "simple" level, a tool is equivalent to a model. However, complex tools can incorporate additional analysis techniques. For example, complex tools can include techniques for incorporating the reported crash history of a specific segment to improve the accuracy of the safety prediction. Complex tools can also include techniques for evaluating alternative designs using safety and other data (e.g., benefit-cost analysis). Tools are sometimes represented in software to facilitate their application.

Safety prediction model is an equation, or set of equations, that can be used to estimate the safety of a typical segment (or intersection). The model includes factors related to crash risk and exposure. A figure or table is sometimes used to portray the relationship (instead of an equation). A model can be derived to include one or more AMFs. Models intended for practical application have one or more empirically based factors that require calibration to local conditions to ensure accurate predictions.

Safety surrogate is any statistic that is directly related to crash frequency or severity (e.g., conflicts) and that quantifies the relative risk of collision or injury.

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2. Bonneson, J., and M. Pratt. *Roadway Safety Design Workbook*. Report No. FHWA/TX-09/0-4703-P2. Texas Transportation Institute, College Station, Texas, July 2009.
3. *Project Development Process Manual*. Texas Department of Transportation, Austin, Texas, 2009.

CHAPTER 2. RESEARCH APPROACH AND DOCUMENTS

OVERVIEW

This chapter provides a brief summary of TxDOT Research Project 0-4703, including its tasks and documents. The project began in fiscal year 2004 with a review of the design and safety evaluation processes employed by TxDOT at the time. The project concluded in fiscal year 2009 with the publication of new guidance to facilitate incorporation of safety considerations and evaluation into the highway design process.

The chapter consists of three sections. The first section describes the research approach. The second section describes the reports and products that were produced over the course of the project. The third section provides some recommended topics for future research.

RESEARCH APPROACH

A six-year program of research was developed to satisfy the project's objectives. The research approach consists of 10 tasks that represent a logical sequence of needs assessment, research, evaluation, and workshop development. These tasks are identified in the following list:

1. Review the TxDOT design and safety evaluation processes.
2. Identify safety information sources and needs.
3. Determine the data needed for selected safety evaluation tools.
4. Evaluate use of accident modification factors for design evaluation.
5. Determine calibration factors for Texas application of safety prediction models.
6. Develop safety documents and conduct research.
7. Develop workshop education materials.
8. Develop an Internet-based safety information resource.
9. Evaluate use of safety evaluation tools by TxDOT staff and refine as appropriate.
10. Conduct meetings and write reports.

This report represents completion of the last five tasks. The reports and products that were written to document the research tasks are described in the next section.

DOCUMENTS

The documents written during the course of this project are categorized as reports and products. Reports describe the research undertaken during the project. Products contain guidance that was developed from the results of the research. The reports and products are listed in Table 2-1 and Table 2-2, respectively.

The eight products identified in Table 2-2 represent the key implementation elements of the project. The *Roadway Safety Design Synthesis* (*Synthesis*) was the first product to be developed, and it provided a compilation of quantitative safety information that was available in published literature at the time of its publication (i.e., November 2005) (*1*). The information from the *Synthesis* was then used to develop the guidance presented in the *Interim Roadway Safety Design Workbook* (*Interim Workbook*) (2).

Table 2-1. Research Reports.

No.	Report Title	Publication Date	Contents
R1	*A Plan for Incorporating Safety into the Highway Design Process*	January 2005	A summary of safety-related design issues and a research implementation plan
R2	*Role and Application of Accident Modification Factors in the Highway Design Process*	May 2005	AMF applications and issues
R3	*[delivered as P1]*	November 2005	See Table 2-2
R4	*Development of Tools for Evaluating the Safety Implications of Highway Design Decisions*	February 2007	Calibration of models for 2-lane rural highways and frontage roads; discussion of information sources and needs
R5	*Calibration Factors Handbook: Safety Prediction Models Calibrated with Texas Highway System Data*	October 2008	Calibration of models for urban and suburban arterial intersections and streets, rural multilane highways, and freeways; some discussion of rural intersection AMFs
R6	*Incorporating Safety into the Highway Design Process: Fifth-Year Report*	August 2008	A summary of the project results and workshop activities
R7	*Development of Safety Performance Monitoring Procedures*	Final Report	Project overview, safety performance monitoring procedure
PSR	*Incorporating Safety into the Highway Design Process: Summary Report*	August 2009	Project summary

Table 2-2. Research Products.

No.	Product Title	Publication Date	Comments
P1	*Roadway Safety Design Synthesis*	November 2005	Compilation of safety information from literature
P2	*Roadway Safety Design Workbook*	July 2009	Final guidance, developed from P1 material and research in R4 and R5
P3	*[delivered as R5]*	October 2008	See Table 2-1
P4	*Interim Roadway Safety Design Workbook*	April 2006	Guidance developed from P1 material
P5	*Procedure for Using Accident Modification Factors in the Highway Design Process*	February 2007	Safety prediction methodology, including empirical Bayes adjustment; analysis procedure, including segmentation guidance
P6	*Rural Two-Lane Highways Workshop Materials*	September 2006	Workshop presentation slides and exercise problems
P7	*Urban and Suburban Arterial Highways Workshop Materials*	November 2007	Workshop presentation slides and exercise problems
P8	*Freeways and Rural Multilane Highways Workshop Materials*	December 2008	Workshop presentation slides and exercise problems

Following the publication of the *Interim Workbook*, research was conducted to develop new safety prediction models using data and study sites in Texas. The results of this research were documented in Reports 4 and 5 (*3*, *4*). The safety prediction models based on the research were compiled in the *Workbook* (*5*). The safety prediction model components (i.e., base models and AMFs) are listed in Table 2-3. There are multiple base models for most facility types, where each alternative base model addresses a different cross section configuration. There are also multiple AMFs for most facility types, where each AMF addresses one geometric design element (e.g., lane width or curve radius).

Products P6, P7, and P8 represent the workshop education materials developed during the project. These products were used in pilot workshops in fiscal years 2007 to 2009. These workshops were conducted to help inform TxDOT engineers and technicians about the new safety guidance that was developed in this project. Material from the *Interim Workbook* was presented at the earlier workshops, and material from the *Workbook* was incorporated as it became available. As indicated in Table 2-2, each workshop focused on safety analysis for one or two facility types.

The workshop materials were also used in workshops for Implementation Project 5-4703, which ran concurrently with Research Project 0-4703 during fiscal years 2007 to 2009. Implementation Project 5-4703 will continue through the end of fiscal year 2010. Workshops conducted in fiscal year 2010 will encompass all guidance documented in the *Workbook*.

RECOMMENDED FUTURE RESEARCH

Future research needs were identified during the later stages of the project and are based partly on the feedback from workshop participants. The research needs are categorized into two areas: (1) facility types for which safety prediction tools are needed and (2) geometric design elements and operational features for which AMFs are needed. The facility types for which safety prediction tools are needed include:

- all-way stop-controlled intersections on rural highways,
- high-speed unsignalized intersections on rural multilane highways and expressways,
- interchange ramps in frontage-road settings, and
- urban frontage roads.

These facility types could not be researched in Project 0-4703, either because little prior research had been conducted on them or because they are less common than the facility types that were included in the *Workbook*. Safety research focusing on these facility types would allow TxDOT to analyze the state's highway network more completely.

The geometric design elements and operational strategies for which AMFS are needed include:

- safety effect of vertical curve flattening on rural highways,
- safety effect of pavement resurfacing on rural highways,
- safety effect of ramp meter operation on ramp and freeway safety,

- safety effect of alternative lane and shoulder width combinations on urban and suburban arterials, and
- safety effect of alternative signal phasing options at urban signalized intersections.

Table 2-3. Safety Prediction Model Components in *Workbook*.

Chapter	Facility Type	Base Models [1]	AMFs [2]
2	Freeways	6: 4- or 6-lane rural; 4-, 6-, 8-, or 10-lane urban	15: Horizontal curve radius, grade, lane width, outside shoulder width, inside shoulder width, median width (no barrier, some barrier, or full barrier), shoulder rumble strips, outside clearance (no barrier, some barrier, full barrier), aggregated ramp entrance, aggregated weaving section, truck presence
3	2-lane rural highways	1	14: Horizontal curve radius, grade, outside clearance (no barrier, some barrier, full barrier), side slope, spiral transition curve, lane and shoulder width, shoulder rumble strips, centerline rumble strip, two-way left-turn lane median type, superelevation, passing lane, driveway density
	4-lane rural highways	3: Undivided, nonrestrictive median, restrictive median	13: Horizontal curve radius, grade, outside clearance (no barrier, some barrier, full barrier), side slope, lane width, outside shoulder width, inside shoulder width, median width (no barrier, some barrier, full barrier), truck presence
4	Urban and suburban arterials	7: 2-lane undivided or nonrestrictive median; 4-lane undivided, nonrestrictive, or restrictive median; 6-lane nonrestrictive or restrictive median	7: Horizontal curve radius, lane width, shoulder width, median width, curb parking, utility pole offset, truck presence
5	Interchange ramps	18: 9 entrance ramp configurations, 9 exit ramp configurations	0
	Frontage roads	1: 2-lane rural	2: Lane width, shoulder width
6	Rural signalized intersections	2: 3-leg or 4-leg	5: Left-turn lane, right-turn lane, number of lanes, driveway frequency, truck presence
	Rural unsignalized intersections	2: 3-leg or 4-leg	8: Left-turn lane, right-turn lane, number of lanes, shoulder width, median presence, alignment skew angle, driveway frequency, truck presence
7	Urban signalized intersections	2: 3-leg or 4-leg	5: Left-turn lane, right-turn lane, number of lanes, right-turn channelization, lane width
	Urban unsignalized intersections	2: 3-leg or 4-leg	7: Left-turn lane, right-turn lane, number of lanes, right-turn channelization, lane width, shoulder width, median presence

Notes:
1 – Numbers indicate the number of base models described in the *Workbook*.
2 – Numbers indicate the number of AMFs described in the *Workbook*.

Some of the proposed new AMF topics focus on design elements or operational treatments that are commonly implemented to improve safety at problem locations. Research would allow the potential benefits of such changes to be known more precisely and used to justify project funding.

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CHAPTER 3. REVIEWING AND DEVELOPING SAFETY PERFORMANCE MONITORING PROCEDURES

OVERVIEW

This chapter documents the development of safety performance monitoring procedures for use in the design process. The procedures were developed based on practices identified following a series of interviews with practitioners within TxDOT and other state departments of transportation (DOTs).

The first section of this chapter summarizes the project development process. The second and third sections synthesize information gathered from the interviews with TxDOT and other state DOT practitioners. The fourth section provides the rationale for the development and evaluation of the safety performance monitoring procedures. The fifth section describes case study applications that were conducted to refine the procedures. Chapter 4 describes the recommended safety performance monitoring procedures.

PROJECT DEVELOPMENT PROCESS

TxDOT's *Project Development Process Manual* provides a detailed flow chart illustrating the project development process (*1*). Figure 3-1 shows a simplified version of this flow chart. The following three major stages of project development are illustrated: planning and programming, preliminary design, and PS&E development. Similar processes are described in manuals from other states (*2*, *3*, *4*).

Planning and Programming
- Identify need and scope
- Prepare cost estimate
- Identify funding

↓

Preliminary Design
- Collect data and prepare preliminary designs
- Select preferred alternative
- Generate geometric schematic
- Conduct value engineering study

↓

PS&E Development
- Design final vertical and horizontal alignment
- Prepare cross sections and compute earthwork
- Prepare all detailed plans (traffic control devices, bridge layouts, hydraulic design, etc.)

Figure 3-1. Project Development Process.

During the three major stages of project development, the *Project Development Process Manual* specifies tasks that involve evaluating or checking safety considerations. The tasks that are relevant to design are listed in Table 3-1.

Table 3-1. Safety-Related Tasks in the *Project Development Process Manual*.

Stage	Task Number	Applicable Project Types	Description of Safety Guidance
Planning and Programming	1000	All	Review crash data to identify facilities with high crash rates relative to similar facilities.
	1200	All	Specify safety improvements indicated by crash data analysis.
Preliminary Design	2190	All except preventative maintenance	Obtain and analyze crash data, geometry, and traffic volume. Look for patterns and identify design features that might reduce crash frequency or severity.
	2350	All new construction and reconstruction, controlled access, or projects needing environmental review	The tools developed in Research Project 0-4703 are available for quantitative safety evaluation.
	2590	Projects with retaining or noise walls	Assess the need for barrier to protect vehicles from rough wall facings. Provide adequate clear zone between walls and travel lanes.
PS&E Development	5240	Projects involving earthwork	Evaluate and modify side slopes and ditch grades to provide for safety and economy of design.

Of the six tasks listed in Table 3-1, the first three provide general guidance, allowing practitioners to use judgment but directing them to use crash data in their evaluations. The last two tasks focus on the specific design elements of clear zone and side slope, respectively. Different safety evaluation methods become feasible as the project development process progresses. For example, it may be too early to quantify the effects of barrier presence during the preliminary design stage because decisions affecting the amount and placement of barrier (i.e., culvert location, side slope, etc.) may not have been made yet. Conversely, by the time a project reaches the PS&E development stage, it may be too late to consider the safety benefits of straightening a sharp curve, as this change may not be feasible within the right-of-way.

INTERVIEWS WITH TEXAS PRACTITIONERS

To gain insight into the role of safety evaluation during design in Texas, interviews were conducted with 18 TxDOT practitioners. The districts and practice areas of these practitioners are given in Table 3-2. Collectively, the practitioners represent a range of knowledge in the different stages of project development, as well as a range of district type (urban or rural) and regional location.

The practitioners were asked questions about how and when safety is evaluated in the different stages of the project development process, how crash data are used in safety evaluation, and which tools are used to assist in the analysis. The scope of the questions includes new construction and reconstruction (4R); and resurfacing, restoration, and rehabilitation (3R) projects. A complete list of the interview questions is provided in the Appendix. A synthesis of information obtained from the practitioners' responses is provided in the following sections.

Table 3-2. TxDOT Practitioners Interviewed.

District	Type	Region	Persons Interviewed	Practice Areas		
				Planning & Programming	Preliminary Design	PS&E Development
Paris	Rural	Northeast	1	✓	✓	
Wichita Falls	Rural	North	1			✓
Abilene	Rural	West	2	✓	✓	✓
Houston	Large urban	Southeast	3	✓	✓	✓
Austin	Small urban	Central	1		✓	✓
San Antonio	Large urban	South	1	✓	✓	✓
Dallas	Large urban	Northeast	1		✓	
Atlanta	Rural	Northeast	1		✓	✓
Beaumont	Small urban	Southeast	1		✓	✓
Pharr	Small urban	South	1		✓	✓
El Paso	Small urban	West	2	✓	✓	
Childress	Rural	North	1		✓	✓

Safety Evaluation in the Design Process

The practitioners were asked when safety is evaluated during the design process. Six practitioners stated that safety is evaluated generally throughout the design process. Four practitioners stated that most safety evaluation occurs during the preliminary design stage, up to the point where the geometric schematics are approved. When asked to specify the project development steps or tasks when safety is evaluated in the design process, the practitioners provided the answers shown in Table 3-3.

Table 3-3. Times when Safety Is Evaluated in the Design Process.

Stage	Step or Task	Number of Responses
All	Throughout entire process	6
Planning and programming + preliminary design	Project development phase (all steps up to geometric schematic approval)	4
Preliminary design	Pre-design meeting	3
	Design summary report	1
	Schematic development	6
PS&E development	PS&E development (general)	2
	30% completion	3
	60% completion	3
	90% completion	1
	95% completion	1
	100% completion	1

When the practitioners were asked how safety is evaluated during design, the most common response was that safe design is achieved by following the standards and criteria in the *Roadway Design Manual* (*5*) and *A Policy on Geometric Design of Highways and Streets* (*Green*

Book) (*6*). Nine practitioners gave this response; one added that his district usually works to achieve designs consistent with the "desirable" standards rather than the "minimum" standards. The practitioners' responses on the considerations in safety evaluation are summarized in Table 3-4.

Table 3-4. Considerations in Safety Evaluation.

Consideration	Number of Responses
Design standards or criteria (minimum or desirable)	9
Driver expectancy, comfort, or ease	3
Concerns expressed by the public	3
Noncompliance / need for design exception	3
Crash data analysis	2
Site-specific knowledge	2
Engineering judgment	1
Traffic operations	1

Following an earlier round of interviews, the value engineering step was identified as a possible time for safety evaluation (*7*). When asked, 10 of the practitioners stated that safety is discussed during value engineering meetings. However, the focus of value engineering is typically on cost-cutting, and while experts in their respective fields (roadway design, bridge design, right-of-way, etc.) are present at the meetings and aware of safety issues, safety experts are seldom present, except if the project is particularly complex.

Safety Evaluation Methods and Tools

The practitioners were asked what methods are used during the design process to identify safety concerns. The three most common responses were site visits, plan reviews, and identification of design elements that are noncompliant with standards and need a design exception. Table 3-5 summarizes the responses to this question.

Table 3-5. Methods Used to Identify Safety Concerns during Design.

Method	Number of Responses
Site visit	5
Noncompliance/need for design exception	5
Plan review	4
Engineering judgment	2
Crash data analysis	2
Public concerns	2
Input from maintenance supervisor, area office, or local jurisdiction	2

When asked about the role of crash data analysis in design, practitioners stated that crash data could be used to identify problems if the crash rate is too high (five responses) or to justify a design exception if the crash rate is low (one response). Two practitioners stated that crash data analysis plays little or no role in the design process. However, nine practitioners stated that crash data analysis plays a vital role in the ranking or prioritization of projects, especially when the projects being considered are eligible for funding from the Hazard Elimination Program (see Chapter 1, Section 3 of Reference *8*).

As shown in Table 3-1, task 2350 in the *Project Development Process Manual* contains a reference to the quantitative safety evaluation tools developed in Project 0-4703. Three of the 18 practitioners were aware of this reference, and two had used the tools. The tools have not been used on any projects that are now completed and open to traffic.

When the practitioners were asked what tools they may find useful in the evaluation of safety, they provided a variety of responses, some of which were beyond the scope of design. Two practitioners stated that they would benefit from a safety checklist that could guide them on checking important design elements. Two practitioners suggested that more mistakes or shortcomings in the design could be identified and corrected if the schematics were reviewed by someone outside the design group that produced the schematics (either other designers, people from other agencies, or practitioners dealing with other relevant issues such as traffic control). Another practitioner stated a desire for a tool that could help TxDOT communicate the benefits of safety improvements to the public or decision makers. He explained that the public generally understands the benefits of projects that increase their convenience by reducing delay but is often less likely to understand the benefits of expending additional resources to achieve safer design.

INTERVIEWS WITH OTHER STATE PRACTITIONERS

Interviews were conducted with practitioners from 10 other state DOTs to identify practices that could be adopted in Texas to enhance the evaluation of safety in the design process. These practitioners had statewide authority and were involved with the design or project development processes. Practitioners from the following states were interviewed:

- Alabama,
- Florida,
- Georgia,
- Kansas,
- Minnesota,
- North Carolina,
- Ohio,
- Oklahoma,
- Washington, and
- Wyoming.

The practitioners were asked questions about how safety evaluation is conducted in the design process and project prioritization. The scope of the questions included 4R and 3R projects, and the questions were more general in nature than the questions for the TxDOT practitioners. A complete list of the interview questions is provided in the Appendix. A synthesis of information obtained from the practitioners’ responses is provided in the following sections.

Safety Evaluation in the Design Process

The design processes in seven of the sampled states do not explicitly incorporate safety. In these states, projects are designed based on *Green Book* or state design manual standards, and safety is implicitly incorporated through adherence to the standards. In one of these states, a design matrix approach is used, where different design matrices exist for different types of facilities (interstate highway, non-interstate highway, interstate interchange, non-interstate interchange, etc.). Facilities serving generally higher volumes or more important functions are built to more generous design standards. In another state, the ranges in the state design manual are on the more generous end of the ranges in the *Green Book*. Practitioners in this state sometimes address safety by designing roadways to standards that are intended for higher-type roadways than that which is being designed. For example, a rural collector with safety concerns might be redesigned to the more generous standards for rural arterials, even if this change would not be justified based on traffic volumes alone.

In the three states that have safety evaluation explicitly incorporated into the design process, procedures differ as to how safety is evaluated. In one state, crash data are analyzed to determine if there are specific locations or crash types that need to be addressed in design, and crash rates among similar corridors are compared to identify corridors that may derive some safety benefit through use of more generous design standards. This analysis is useful both for project prioritization and for identification of design deficiencies that can be corrected in a rehabilitation or reconstruction project.

In a second state, a detailed safety review is conducted for all major projects, and a generalized safety review is conducted for all other projects, including repaving projects. In this state, a formalized training course is offered to all consultants on how to identify problem locations on major facilities. Problem locations are identified based on the amount by which the facility's crash rate exceeds the average rate for similar facilities, and countermeasures may be identified based on patterns in crash type. A major project is defined as a project costing $5 million or more.

In a third state, a project safety review has recently been added to the design process for 3R projects. It occurs during the scoping of the project and involves some prediction of safety performance based on geometric design elements, in addition to the typical review of crash history. The prediction of safety performance based on geometric design elements is a relatively recent addition to the design process for this state and is conducted using the information provided in Transportation Research Board (TRB) *Special Report 214* (*9*).

The practitioners named a variety of tools that they have either used regularly to evaluate safety, or that they would find useful. These tools are listed in Table 3-6. Four practitioners stated that they are waiting for the *Highway Safety Manual* to be released. However, another practitioner expressed doubts that the *Highway Safety Manual* would produce reliable results and stated that he would like to see some thorough validation before using it. Two practitioners observed that the Interactive Highway Safety Design Model only works for 2-lane highways and expressed a desire to see it expanded to other roadway types. Another practitioner stated that automated data importation is a useful feature that facilitates widespread implementation.

Table 3-6. Tools Used or Needed for Safety Evaluation.

Safety Evaluation Tool	Number of Responses
Highway Safety Manual	4
Interactive Highway Safety Design Model	4
Interim Roadway Safety Design Workbook (Project 0-4703)	1
National Cooperative Highway Research Program 500 report series	1
Roadside Safety Analysis Program (RSAP)	1
SafetyAnalyst	1
Traffic Safety Toolbox	1
TRB *Special Report 214*	1

Safety Considerations in Project Prioritization

Practitioners in all 10 of the sampled states consider safety in the ranking and prioritization of projects. Though the procedures for project prioritization vary across the states, there was general consensus that if it can be demonstrated that a given facility has a higher crash rate than similar facilities in the state, it is easier to obtain funding and approval for a project to improve that facility. Safety evaluation that leads to higher project prioritization would occur early in the design process, during planning and programming.

One practitioner mentioned that maintenance data are also used to evaluate safety in project prioritization. For example, if a given facility does not have a high crash rate, but maintenance personnel report that they frequently observe scuff marks on barriers or have to repair guardrail, then that facility may be identified as having potential for safety improvement.

Use of Road Safety Audits

The American Association of State Highway and Transportation Officials (AASHTO) describes a road safety audit as "a formal safety performance examination of an existing or future road or intersection by an independent audit team" (*10*). The audit is typically conducted by a three- to five-person interdisciplinary team, with the goal of identifying potential hazards before crash patterns emerge. The *Canadian Road Safety Audit Guide* includes procedures for conducting roadway safety audits in parallel with value engineering studies (*11*).

Four of the 10 sampled states conduct road safety audits on an ongoing basis. Practitioners in these states conduct road safety audits mostly on in-service facilities. Typical conditions indicating the need for an audit include safety or operational concerns, requests from a district or local office, or high degrees of geometric complexity. In one case, practitioners conducted an audit of a roadway that was known to have safety problems but did not have any obvious geometric design flaws that would explain the crash history.

Practitioners in a fifth state conducted stand-alone road safety audits in the past, but later subsumed these types of evaluations into the state's Corridor and Intersection Safety Programs. These programs incorporate crash data analysis and feedback from citizen advisory committees to identify facilities that may benefit from safety improvement. Practitioners in a sixth state conduct audits in conjunction with the Hazard Elimination Program. Their objective is to identify sites that need safety improvement.

PROCEDURE DEVELOPMENT

Need for Safety Performance Monitoring

Safety performance monitoring is needed at every stage of the project development process. The goal of safety performance monitoring is to ensure that limited resources are allocated in an efficient manner to achieve goals for safety improvement (i.e., reduction in crash frequency). Safety performance monitoring procedures assist the practitioner in quantifying the safety effects of design elements, such that safety can be considered along with construction cost, operational efficiency, and environmental impacts.

Figure 3-2 illustrates the role of safety evaluation in the project development process. This role evolves as the project development process progresses through the three stages. For instance, during the planning and programming stage, several different facilities may be under consideration for improvement. The analyst would quantify the overall safety performance (and other performance measures) associated with each existing facility. The facility with greatest potential for improvement would then be identified. The crash history associated with each facility would be used for this evaluation. As appropriate, it could also be used to identify areas within a facility that have a notable potential for crash reduction. A "facility" represents an entire project area plus any peripheral intersections or roads that may be influenced by the project.

In the preliminary design stage, the project manager may need to quantify the safety performance (and other performance measures) associated with each of several alternative designs so that the most cost-effective alternative can be identified. The safety evaluation in this stage will address specific design components that are known to have some influence on safety. These components may include alternative routes, typical cross section, horizontal alignment, vertical alignment, median type, intersection geometry and traffic control mode, lighting, etc.

In the PS&E stage, members of the design team may need to quantify the safety performance (and other performance measures) associated with various alternative design elements. The safety evaluation in this stage will address specific design elements at specific locations where circumstances suggest a likely influence on safety. These elements may focus on a specific retaining wall location, crosswalk location, driveway, barrier location, side slope, or ditch cross section.

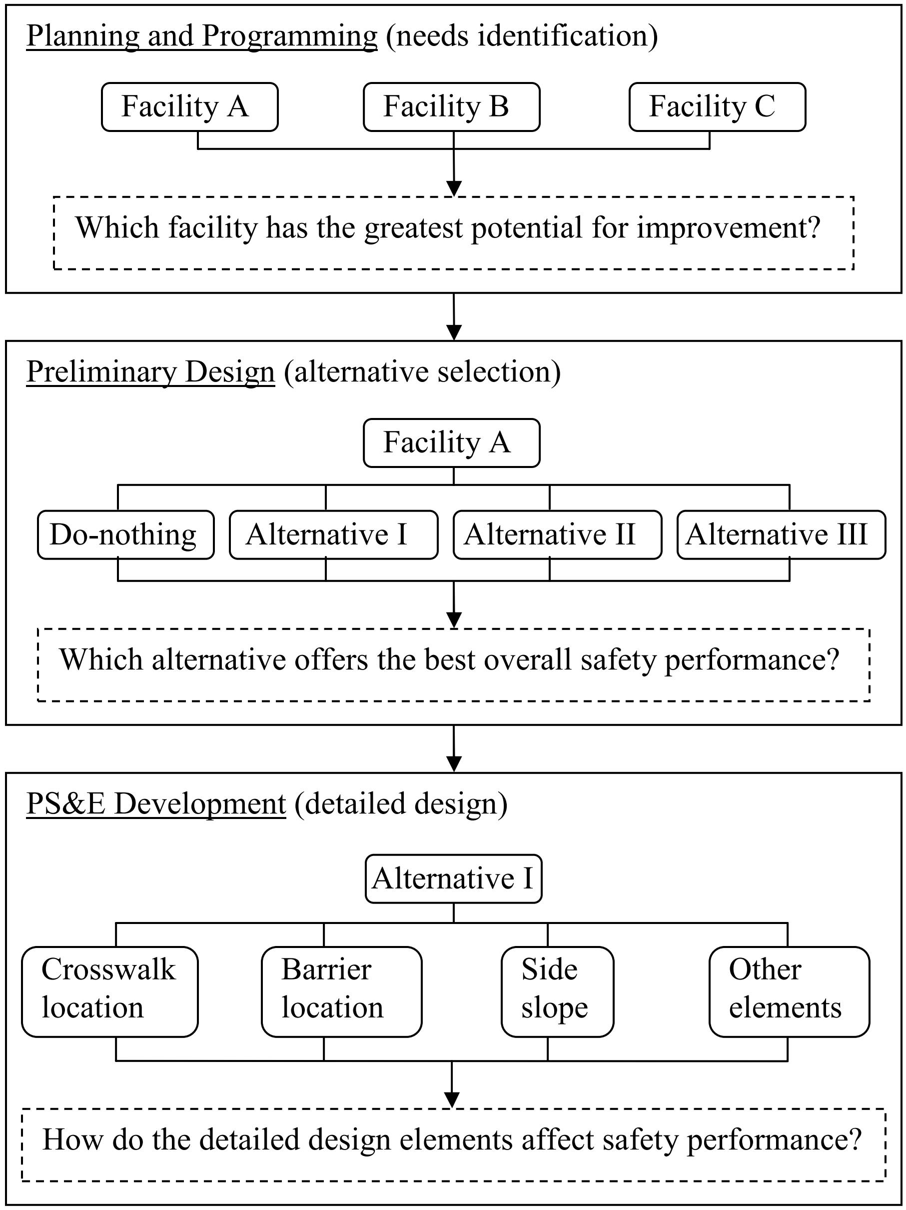

Figure 3-2. Safety Evaluation in the Project Development Process.

Safety Evaluation Types

The safety evaluation described in this section is based on the use of a safety prediction methodology, such as that described in the *Procedure for Using Accident Modification Factors in the Highway Design Process* (*12*). This methodology involves the use of safety prediction models to individually evaluate each of the various roadway segment or intersection types that comprise a facility. These models consist of the following three main components:

- Base models provide an estimated expected crash frequency for a facility with typical or "base" conditions.
- AMFs allow the estimated expected crash frequency to be modified if conditions deviate from the typical or base conditions.
- Empirical Bayes (EB) adjustment allows the estimated expected crash frequency to be refined using crash history data.

Base models, AMFs, and base conditions for a variety of facility types are documented in the *Workbook* (*13*).

Alternative types of safety evaluation are available during each stage of the project development process. These types reflect a complexity of analysis that is consistent with the level of detail needed at each stage. The four basic types of evaluation are described as: basic, basic-EB, detailed, and detailed-EB. Table 3-7 summarizes the safety evaluation types.

Table 3-7. Safety Evaluation Types.

Evaluation Type	Model Component(s) Used			Description	Applicable Stage of Project Development Process
	Base Models	AMFs	Empirical Bayes Adjustment		
Basic	Yes	Some	No	Estimate the expected crash frequency for a "typical" facility, with some sensitivity to site-specific constraints like grade and horizontal alignment.	Planning and Programming
Basic-EB	Yes	Some	Yes	Estimate the expected crash frequency for a "typical" facility, with some sensitivity to site-specific constraints like grade and horizontal alignment. Use crash data to refine the estimate.	Planning and Programming
Detailed	Yes	Yes	No	Estimate the expected crash frequency for a specific facility by using all relevant AMFs.	Preliminary Design; PS&E Development
Detailed-EB	Yes	Yes	Yes	Estimate the expected crash frequency for a facility by using all relevant AMFs. Use crash data to refine the estimate.	Preliminary Design; PS&E Development

The two main types of safety evaluation are the basic and the detailed evaluation. The basic evaluation uses primarily the base models described in the *Workbook*, with a very limited number of AMFs. The decision to use an AMF in a basic evaluation is based on consideration of the availability of the needed data and the additional accuracy obtained in the estimated expected crash frequency.

The detailed evaluation uses the complete safety prediction model (i.e., the base model and the full complement of AMFs). This level of evaluation requires more data but provides a more accurate estimate of expected crash frequency.

Either the basic or the detailed evaluation can be coupled with the EB adjustment procedure. This procedure combines the expected crash frequency from a model with the reported crash history to obtain a more accurate estimate of the expected crash frequency for the subject road segment or intersection.

Candidate Safety Performance Monitoring Procedure

A candidate safety performance monitoring procedure is described in this section. This procedure describes where, when, and how engineers can evaluate safety in the project development process. The procedure is described as a series of steps that would be repeated during each stage of the project development process. The activities associated with each step tend to vary slightly for each stage in recognition of the different scope and level of detail associated with each stage. This procedure is focused on monitoring and maintaining the safety performance of a design as it advances through the design process. It is assumed that decisions reached at any stage are based on consideration of the full range of design impacts, of which safety impact is one of many possible factors considered.

The candidate safety performance monitoring procedure consists of the following steps:

1. define evaluation scope,
2. recruit technical expertise,
3. identify project features to evaluate,
4. gather data,
5. conduct evaluation, and
6. document findings and decisions.

A brief overview of the activities undertaken during each step is provided in Table 3-8.

Table 3-8. Safety Performance Monitoring Procedure Activities.

Procedure Step	Description
1. Define Evaluation Scope	The scope of the safety evaluation should be defined in terms of the facility being considered for construction, reconstruction, or resurfacing.
2. Recruit Technical Expertise	The project manager should identify the expertise needed for the safety evaluation. These individuals should collectively have experience in areas related to the project's design, operation, and maintenance.
3. Identify Project Features to Evaluate	The technical team established in the previous step would identify the specific project features for which a safety evaluation is needed.
4. Gather Data	The technical team will gather the data needed to evaluate the safety of the project features identified in the previous step. These data will include the crash history (and crash location), geometry, and traffic volume.
5. Conduct Evaluation	Selected members of the technical team would conduct a safety evaluation for the project features identified in Step 3. Table 3-1 describes potential opportunities for this evaluation in each stage of the project development process.
6. Document Findings and Decisions	The technical team documents the findings from the previous steps and the decisions made in a technical memorandum to the District Engineer.

CASE STUDY APPLICATIONS

This section describes case study applications that were conducted to evaluate and refine the candidate procedure. The case study applications illustrate potential opportunities for safety evaluation during the different stages of the project development process. They also illustrate the appropriate safety evaluation types for each evaluation opportunity.

Case Study Project Descriptions

Case studies were conducted for five projects that were recently completed or under construction by TxDOT. Two of the projects were classified as 3R, and three were classified as 4R. These projects were located within the TxDOT Bryan and Houston districts. The districts provided traffic, geometric, and crash data for the projects. General descriptions of the projects are provided in the first two columns of Table 3-9.

Table 3-9. Case Study Projects and Analyses.

Roadway	Project Description	Evaluation Type	Stage	Analysis Scenario(s)
Urban street segment A	Add a raised-curb median to a 6-lane urban street. (3R)	Detailed-EB	Preliminary Design	1. Do-nothing—predict crash costs if no change is made. 2. Alternative—predict crash costs if a raised-curb median is added.
Urban street segment B	Widen a 4-lane urban street to 6 lanes with a raised-curb median. (4R)	Detailed	Preliminary Design	1. Alternative 1— predict crash costs if 2 lanes are added. 2. Alternative 2— predict crash costs if a raised-curb median is added along with the new lanes.
US Highway 190	Widen shoulders on a 2-lane undivided rural highway. (3R)	Basic	Planning and Programming	1. Do-nothing—predict crash costs if no change is made. 2. Alternative—predict crash costs if the shoulders are widened.
Interstate 45	Widen a 4-lane urban freeway to 8 lanes. (4R)	Detailed-EB	Preliminary Design	1. Do-nothing—analyze a portion of the facility requiring a design exception. 2. Alternative—determine how the crash cost would change if the conditions requiring the design exception were eliminated.
Interstate 10	Widen a 4-lane urban freeway to 6 lanes. (4R)	Detailed	PS&E	1. Analyze a complex part of the facility to identify design components for possible improvement.

The following subsections provide detailed descriptions of each case study project and the analysis scenarios that are summarized in the last column of Table 3-9. Each analysis scenario involved predicting crash frequency for one combination of geometry and traffic volume for a specific time period (i.e., before or after construction) and then using these crash frequencies to determine crash costs. The crash frequencies were predicted using the safety prediction models described in the *Workbook*.

For four of the projects, some type of alternatives analysis was conducted, either to compare the chosen alternative to the "do-nothing" alternative or to compare two alternative designs that were considered. For these projects, there are two analysis scenarios. Hence, a total of nine scenarios were analyzed. An alternatives analysis was not conducted for the fifth project (Interstate 10) because the analysis scenario for this project represented a safety evaluation that would be conducted during the PS&E stage. By the time a project reaches the PS&E stage, the desired project alternative has already been chosen, and the remaining design decisions are relatively small and focused in nature.

Urban Street Segment A

Urban street segment A has six lanes and a two-way left-turn lane (TWLTL) median and is 0.72 miles long. The project involved adding a raised-curb median to the street segment. The ADT for the facility was 52,000 veh/d before construction and was projected to increase by 1000 veh/d for each of the next 20 years.

Two scenarios were analyzed for this project. First, the future crash frequency was predicted using the roadway's existing geometry and the projected ADT. This crash frequency represents the expected safety performance associated with the do-nothing option. Second, the future crash frequency was predicted using the roadway's proposed geometry (i.e., added raised-curb median) and the projected future traffic volume.

The predicted crash frequencies for the two scenarios were compared to determine the expected safety benefit associated with the project. The construction cost was also used in a cost-benefit analysis to determine the project's net safety benefit. Because crash data were available and the facility was not undergoing major physical changes, the EB adjustment was used to refine the predicted crash frequencies for both scenarios. The evaluation type was detailed-EB. This type of analysis would likely occur during the earlier steps of the preliminary design stage when alternatives are being considered.

Urban Street Segment B

Urban street segment B has four lanes and a TWLTL median and is 1.04 miles long. This segment connects to urban street segment A. The project involved adding two lanes and a raised-curb median to the street segment. The ADT of the facility was 52,000 veh/d before construction and was projected to increase by 1000 veh/d for each of the next 20 years.

Two scenarios were analyzed for this project. First, the future crash frequency was predicted for an alternative involving only the addition of lanes. Second, the future crash frequency was predicted using the roadway's proposed geometry (i.e., six lanes and raised-curb median). The costs of both alternatives were also estimated and used in an incremental cost-benefit analysis to determine the net benefit of the second alternative with respect to the first.

These analyses represent detailed evaluations. EB adjustment could not be used because the second alternative involved adding lanes. This type of analysis would be conducted during the earlier steps of the preliminary design stage.

US Highway 190

US Highway 190 is a 2-lane undivided rural highway in rolling terrain. The project involved widening the roadway's shoulders from 1 ft to 10 ft along a 5.1-mile portion of the highway. The ADT for the facility was projected to increase to 15,000 veh/d at the end of the project's service life.

Two scenarios were analyzed for this project. First, the future crash frequency was predicted using the roadway's existing geometry and the projected ADT. This crash frequency represents the expected safety performance associated with the do-nothing option, if no geometric changes were made but traffic volumes grew as projected. Second, the future crash frequency was predicted using the roadway's proposed geometry (i.e., widened shoulders) and the projected future traffic volume. These analyses represent basic evaluations (see Table 3-7), which may be conducted with the limited data available in the planning and programming stage. Similar analyses would be conducted on any other facilities under consideration for improvement, in addition to the US Highway 190 facility being described here.

The predicted crash frequencies for the two scenarios were compared to determine the expected safety benefit associated with the project. The construction cost was also used in a cost-benefit analysis to determine the project's net safety benefit. Only the following key geometric elements were considered: number of driveways, grade, lane width, outside shoulder width, and horizontal clearance. Approximate values for these elements were used because precise data are not yet available in the planning and programming stage. These elements were considered because they allowed the facility to be described more precisely (number of driveways, grade) or they were being considered for improvement (lane width, outside shoulder width, horizontal clearance).

Interstate 45

Interstate 45 is a 4-lane urban freeway. The project involved adding four lanes in the median of the freeway. The ADT of the facility before construction was 92,900 veh/d. The segment of interest was a short (0.16 miles) bridge approach that required a design exception because its grade (3.26 percent) was slightly steeper than the maximum grade allowed by standards (3 percent). For this project, two detailed-EB analyses were conducted to quantify the expected crash frequencies for the segment with and without the steep grade requiring the design exception. These analyses represent analysis scenarios 1 and 2, respectively.

Interstate 10

Interstate 10 is a 4-lane urban freeway. The project involved adding two lanes and reconstructing ramps along an 8-mile portion of the freeway. The ADT of the facility before construction was 47,500 veh/d.

For this project, a detailed evaluation was conducted on a complex 0.65-mile segment of the facility. This segment passed through a service interchange, had horizontal curvature, and had several portions of barrier where the freeway mainline passed over the cross street on bridges. This segment was targeted for analysis to determine which of its geometric elements could yield safety benefits if improved.

Because this analysis targets a complex segment of the facility to be upgraded, data would need to be collected for all geometric design elements. This type of analysis could be conducted during the PS&E stage to assess the safety implications of design decisions made during that stage.

Economic Analysis Procedure

An economic analysis was conducted for each of the projects listed in Table 3-9. This analysis involved computing the reduction in crash frequency that would occur in each year of the project's design life, determining the present value of these crash reductions, and comparing them to the project construction cost. This section describes the economic analysis method.

First, the safety benefit for each year of the project's design life was calculated as shown in Equation 1.

$$B_n = \text{Cost}\ (C_{2,n} - C_{1,n}) \tag{1}$$

where,

B_n = safety benefit for year n, \$;
n = year number, 0, 1, 2, …, design life in years;
$C_{1,n}$ = crash frequency for alternative 1 and year n;
$C_{2,n}$ = crash frequency for alternative 2 and year n; and
Cost = average societal cost of a combined injury and fatal crash (use \$100,000), \$.

Each calculated B_n represents a safety benefit for a given year n, and hence is a future value. Equation 2 is then used to convert these future benefits to their equivalent present values and to determine the total present value of the project's safety benefit.

$$P = \sum_{n=0}^{20} B_n (1+i)^{-n} \tag{2}$$

where,

P = total present value of safety benefit, \$; and
i = real ("inflation-removed") discount rate (= 4.75 percent), percent.

The real discount rate i was calculated assuming a bank rate of 10 percent and an inflation rate of 5 percent. This quantity represents the opportunity cost of capital for an investment, which is appropriate for converting benefits and costs of a project to their present value (*14*, *15*).

If there is only one alternative or there are multiple alternatives each with the same design life, then the present value of the safety benefit is compared with present value of construction costs using the benefit-cost ratio. If there are multiple alternatives with differing design lives, then the capital recovery formula is used to compute the equivalent uniform annual safety benefits and the equivalent uniform annual construction cost for each alternative (and its respective design life). Alternatively, an equivalent annual cost approach can be consistently used for all economic analyses, thus eliminating the concern about design life differences.

When funds can be spent on any facilities under consideration, the benefit-cost ratio should be used to select projects. Conversely, if funds are earmarked for a specific facility, an incremental cost-benefit analysis or a comparison of net benefits should be conducted to choose the most beneficial project alternative for that facility (*14*).

Findings

The total crash costs (i.e., costs associated with the predicted injury [plus fatal] crash frequencies) for the nine case study project scenarios are provided in the fifth column of Table 3-10. Benefit-cost (B/C) ratios were computed for three of the projects and are shown in the sixth column of Table 3-10. These benefit-cost ratios represent considerations of safety performance and construction cost only. Other considerations (operational efficiency, environmental and community impacts, right-of-way availability, etc.) are important, but are beyond the scope of the case study applications. The combined AMFs provided in the eighth column of Table 3-10 represent the product of all individual AMFs used in the evaluation of the scenarios.

Table 3-10. Case Study Scenario Analysis Results.

Project	Analysis Scenario	Design Life, yr	Construction Cost	Total Crash Cost	B/C ratio	Net Benefit	Combined AMF
Urban street segment A [1]	1	--	$0	$31,930,000	--	--	0.95
	2	20	$6,700,000	$20,490,000	1.07	$490,000	1.01
Urban street segment B [2]	1	20	$7,300,000	$46,980,000	--	$570,000	0.90
	2	20	$10,400,000	$40,760,000	1.26	$1,380,000	1.00
US Highway 190 [1]	1	--	$0	$31,380,000	--	--	1.35
	2	25	$4,400,000	$20,630,000	1.37	$1,620,000	1.14
Interstate 45	1	25	--	$11,380,000	--	--	3.54
	2	25	--	$11,330,000	--	--	3.52
Interstate 10	1	25	--	$15,930,000	--	--	3.33

Notes:
"--" = Not applicable
1 – Analysis scenario 1 represents the do-nothing option.
2 – The B/C ratio reported for this project is an incremental B/C ratio.

The findings for each project are discussed in greater detail in the following subsections.

Urban Street Segment A

Using the safety prediction models documented in the *Workbook*, crash frequencies were calculated for both analysis scenarios for each of the 20 years in the project's design life. The input data needed to perform this calculation are not presented here, as the focus of this discussion is economic evaluation of costs and benefits.

Safety benefits were computed using Equation 1 for each of the 20 years in the project's design life. These safety benefits were then summed and converted to equivalent present value using Equation 2. This process was repeated for all of the scenarios listed in Table 3-10.

With no changes made to the segment, the 20-year crash cost for the segment was $31,930,000. With a raised-curb median added to the segment, the 20-year crash cost was $20,490,000. The total present value of this crash cost reduction was $7,190,000. The project's construction cost was $6,670,000, yielding a B/C ratio of 1.07 and a net benefit of $490,000.

Urban Street Segment B

The total crash cost following the addition of lanes was $46,980,000, with a combined AMF of 0.90. The total crash cost associated with adding lanes and a raised-curb median was $40,760,000, with a combined AMF of 1.00. An incremental cost-benefit analysis was conducted to determine whether this additional safety benefit justified the added cost of providing the raised-curb median.

The construction costs for the project alternatives evaluated in scenarios 1 and 2 were $7,300,000 and $10,400,000, respectively, yielding an incremental cost of $3,100,000 for the raised-curb median. The present values for the alternatives were $7,870,000 and $11,780,000, respectively, yielding an incremental benefit of $3,910,000 for the raised-curb median. The resulting incremental B/C ratio is 1.26, which indicates that the raised-curb median yields a greater benefit than just adding the lanes. The same result is shown by the greater net benefit for scenario 2 than for scenario 1 ($1,380,000 versus $570,000).

US Highway 190

Analysis Scenario 1—Do-Nothing Option. The total crash cost over 25 years was $31,380,000. Though the grade varied along the length of the facility, a grade of 2.5 percent was used in the modeling of the facility. This value represented the average grade observed along the facility. Approximations of this nature are acceptable for an analysis conducted during the planning and programming stage, when detailed data are not yet available.

The combined AMF (i.e., the product of all individual AMFs) was 1.35, indicating that their crash frequency is 35 percent higher than that for similar facilities having "base" conditions. An examination of the individual AMFs for the key design elements helped identify changes that could improve the safety performance of the facility. The calculated values for the individual AMFs are provided in the second column of Table 3-11.

Table 3-11. Individual AMFs for US Highway 190.

Key Design Element	AMF	
	Analysis Scenario 1	Analysis Scenario 2
Grade	1.04	1.04
Outside clearance (no barrier)	1.14	1.13
Lane and shoulder width	1.13	0.97

All three of the AMFs in the second column of Table 3-11 have values greater than 1.0, but the AMFs for outside clearance and for lane and shoulder width are the largest. The larger AMFs indicate that design improvements to these geometric design elements could yield the largest potential improvement in the safety performance of the facility.

Analysis Scenario 2—Shoulder Widening Project. After the increased shoulder widths were incorporated into the calculations, the combined AMF decreased to 1.14 (compared to 1.35 for Analysis Scenario 1, the do-nothing option). The individual AMFs for the key design elements changed as shown in the third column of Table 3-11. The AMF for lane and shoulder width decreased from 1.13 to 0.97, and the AMF for outside clearance decreased slightly from 1.14 to 1.13. As a result of the geometric improvements, the expected 25-year crash cost for the analyzed segments dropped to $20,630,000.

Cost-Benefit Analysis. A cost-benefit analysis was conducted to determine whether the shoulder widening project was an economically viable option compared to the do-nothing option. A design life of 25 years was assumed for the project.

The present value of the safety benefit over the design life was $6,020,000. The construction cost of the project was $4,400,000, resulting in a B/C ratio of 1.37 (= $6,020,000 ÷ $4,400,000) and a net benefit of $1,620,000 (= $6,020,000 – $4,400,000) over the life of the project.

Interstate 45

The 25-year crash cost was $11,380,000 with the design exception (i.e., grade of 3.26 percent) and $11,330,000 without the design exception (i.e., grade of 3 percent). Given the small change in grade, this small change in crash cost is expected.

This analysis verifies that the design exception's effect on the facility's safety performance is minor. No benefit-cost analysis was conducted, but it is unlikely that the changes required to eliminate this design exception would have been justified. Reducing the grade to 3 percent would have required replacing a large bridge that was in good structural condition and was not approaching the end of its service life.

Interstate 10

The 25-year crash cost for the analyzed segment was $15,930,000, with a combined AMF of 3.33. This combined AMF indicates that the analyzed segment has a crash frequency notably higher than that for a segment with "base" conditions. As was previously noted, there are three factors that combine to make this segment "complex": horizontal curvature, presence of interchange ramps, and presence of bridges. Specifically, the mainline roadbeds pass over the cross street on separate bridges, which makes it necessary to provide barrier along both sides of each bridge.

The following AMFs can be calculated to determine the effect of these design elements on safety performance: horizontal curve radius, aggregated ramp entrance, median width (some barrier), and outside clearance (some barrier). These AMFs are provided in Table 3-12.

Table 3-12. Individual AMFs for Interstate 10.

Key Design Element	AMF
Median width (some barrier)	1.64
Outside clearance (some barrier)	1.53
Aggregated ramp entrance	1.08
Horizontal curve radius	1.01

The two AMFs with the largest values are for median width (some barrier) and outside clearance (some barrier). The values for these AMFs are 1.64 and 1.53, respectively. These AMFs account for the safety effects of the median width and the horizontal clearance, as well as the presence of barrier in the median or on the roadside. The use of barrier on this segment was necessary because of the presence of the bridges. However, the high values for these AMFs reveal that safety performance could be improved significantly if the barrier presence were mitigated in the design of the new facility. One method to accomplish this goal would be to replace the two bridges with a single bridge that accommodates wider shoulders.

Based on the AMFs, the presence of the ramp entrance appears to have a moderate effect on the safety performance of the segment, and the effect of the horizontal curvature is minor. Hence, these design elements may be considered less of a priority for improvement.

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CHAPTER 4. SAFETY PERFORMANCE MONITORING PROCEDURE

OVERVIEW

This chapter describes a safety performance monitoring procedure for use in TxDOT's project development process (*1*). The procedure was developed based on the case study applications described in Chapter 3.

DESCRIPTION OF PROCEDURE

The safety performance monitoring procedure consists of the following steps:

1. define evaluation scope,
2. recruit technical expertise,
3. identify project features to evaluate,
4. gather data,
5. conduct evaluation, and
6. document findings and decisions.

The following paragraphs provide a brief overview of the activities undertaken during each step. In some instances, the specific activities or information will vary, depending on the stage of the design process in which the procedure is being conducted.

1. Define Evaluation Scope. The scope of the safety evaluation should be defined in terms of the facility being considered for construction, reconstruction, or rehabilitation. At the planning and programming stage, the scope would likely include the limits of the project. This scope would also apply to the preliminary design stage; however, the individual components would be evaluated in greater detail. At the PS&E stage, the scope is likely to include only specific road segments or intersections. Specification of scope includes identification of geographic limits, travel modes (e.g., cars, trucks, transit, pedestrian, bicycle, etc.), functional class, and design life.

2. Recruit Technical Expertise. During this step, the project manager should identify the expertise needed for the safety evaluation. These individuals should collectively have experience in areas related to the project's design, operation, and maintenance. At least one member of the team should be able to address safety issues for each travel mode identified in the previous step. The safety evaluation team should include the project manager, design team leader, and key designers. It may also include a traffic safety specialist and maintenance supervisor as well as TxDOT individuals with expertise in the area of transit, pedestrian, or bicycle accommodations. In this regard, TxDOT division resources may be needed when these individuals are not available in the district.

3. Identify Project Features to Evaluate. During this step, the technical team established in the previous step would identify the specific project features for which a safety evaluation is needed. As noted previously in the discussion associated with Figure 3-2, the types of features that would be considered for evaluation will depend on the stage of the design process for which the evaluation is being conducted.

For the planning and programming stage, the overall expected crash frequency of each existing facility is quantified. As appropriate, the crash history could also be used to identify areas within a facility that have a notable potential for crash reduction. Designers typically strive to meet desirable standards as opposed to minimum standards for new facilities. Accordingly, compliance with desirable standards should be assumed when evaluating new facilities during this stage.

For the preliminary design stage, the evaluation will focus on the specific design components of each alternative that are known to have some influence on safety. These components may include typical cross section, horizontal alignment, vertical alignment, median type, intersection geometry and traffic control mode, lighting, channelization, access point spacing, bicycle lane, parking lane, etc. Design dimensions associated with these components that are constrained by a "controlling criterion" (i.e., a criterion that if not adhered to will dictate the need for a design exception) are candidates for evaluation (*2*).

For the PS&E stage, the evaluation will focus on specific design elements at specific locations where circumstances suggest a likely influence on safety. These elements may focus on a specific retaining wall location, transit stop, crosswalk location, driveway, barrier location, or ditch cross section. Roadway locations where atypical conditions exist, the design is complex, or construction costs are unusually high may be candidates for reevaluation.

4. Gather Data. During this step, the technical team will gather the data needed to evaluate the safety of the project features identified in the previous step. These data will include the crash history (and crash location), geometry, and traffic volume. The data collected will vary, depending on the location (which is dependent on the stage in the design process). For example, during the planning and programming stage, the data may consist of overall crash count, ADT for the route, basic number of lanes, and project length. For the preliminary design stage, the data may consist of crash history by manner of collision, design hourly volumes, curve radius and length, bay length, shoulder width, etc. For the PS&E stage, the data may include barrier length and location, side slope, horizontal clearance, and ditch cross section. The geometric and traffic data collected in this step would apply to both the existing and proposed projects.

A possible field visit to the existing facility should be considered during this step. During this visit, the technical team would identify and discuss potential safety issues. The influence of the topography and development on the existing and the proposed designs should be assessed. If a field visit is not feasible, then a "virtual" visit using a video log may be a reasonable alternative.

5. Conduct Evaluation. During this step, selected members of the technical team would conduct a safety evaluation for the project features identified in Step 3. Table 4-1 describes potential opportunities for this evaluation in each stage of the project development process. The second and third columns of the table indicate the evaluation type and scope for each stage and step within the process. For example, a basic or basic-EB evaluation is suggested for existing facilities that are being considered for upgrade in task 1000. This evaluation would compare a given facility's safety performance with that of similar facilities and provide insight into which of the considered facilities could benefit most from safety-related treatments.

Table 4-1. Safety Evaluation Opportunities in the Project Development Process.

Stage	Evaluation Type	Evaluation Scope	Step	Task No.	Purpose or Use of Evaluation
Planning and Programming	Basic or Basic-EB	Existing facilities	Needs Identification	1000	Determine which facilities have crash frequencies high enough that they can benefit from safety improvement.
			Project Authorization	1200	Identify geometric element changes that could reduce crash frequency. The expected costs of these geometric changes can then be considered to determine project feasibility.
Preliminary Design	Detailed or Detailed-EB	Facility to be upgraded	Data Collection/ Preliminary Design Preparation	2190	Determine which geometric design changes would most effectively reduce crash frequency.
			Public Meeting(s)	2260	Use the evaluation results to communicate the need for geometric improvement to the public.
	Detailed or Detailed-EB	All alternative designs	Preliminary Schematic	2300 2320	Determine facility type, approximate grade, and horizontal alignment (including horizontal curve radii) for the corridor and route alternatives, and consider the safety effects of these variables.
				2350	Use the estimated expected crash frequencies for each alternative to assist in the identification of a preferred alternative. Consider the effects of grade and horizontal alignment, which may differ for the different alignments being considered. Use the estimated expected crash frequencies for each alternative to conduct an economic comparison of the alternatives.
	Detailed or Detailed-EB	Preferred alternative	Geometric Schematic	2580 2590	Quantify the lengths of bridge abutments and noise walls needed. Consider the safety effects of these barriers.
			Value Engineering	2700 2710	Identify elements that could yield lower crash frequency if improved, and suggest revisions to the preliminary design based on these findings.
PS&E Development	Detailed or Detailed-EB	Preferred alternative	Final Alignments/ Profiles	Various	Continue to update and refine the detailed evaluation of the chosen alternative as design decisions on the geometric elements are made. Adjust the geometric elements if necessary.
			Roadway Design	5240	Quantify the change in crash frequency that could occur if side slope is altered.
			Operational Design, Bridge Design, Drainage Design, Retaining/ Noise Walls and Misc. Structures	Various	Total up the amount of barrier that would be required for the illumination, bridge structures, culverts, and retaining walls that are chosen, and quantify the effect of the barriers on crash frequency. Revise barrier placement accordingly.

The results of a detailed or detailed-EB evaluation are suggested for use in the preliminary design stage. In task 2190, the results are used to identify design elements at a given facility that could yield improved safety performance if changed. They are also used in task 2260 to communicate the benefits of safety improvements to the public during the conduct of public meetings.

Table 4-1 suggests the need for a detailed or detailed-EB evaluation of all alternative facility designs under consideration in tasks 2300, 2320, and 2350. The purpose of these analyses is to obtain an estimated expected crash frequency for each alternative, with some sensitivity to site-specific geometric constraints like grade and horizontal alignment, but otherwise assuming that design elements are similar to base conditions for the facility type.

Table 4-1 also suggests the need for a detailed or detailed-EB evaluation of the preferred alternative in tasks 2700 and 2710. These results should be updated during the PS&E development stage.

The evaluation process can be particularly helpful for evaluating design exceptions and justifying design exception requests. The safety evaluation tools can be used to quantify the expected safety effects of design exceptions, and this information can then be used to determine whether the design exception should be pursued through the submission of a formal design exception request.

6. Document Findings and Decisions. During this step, the technical team documents the findings from the previous steps and the decisions made in a technical memorandum to the district engineer. An introductory section should briefly describe the project, list the analysis scope, and specify the project limits. The next section should describe the background information related to the identified safety issues and constraints. This section should also identify the technical team members. The last section should summarize the design features evaluated, data collected, evaluation results, and decisions made. Drawings or diagrams should be included where appropriate.

GUIDANCE

The following subsections provide additional guidance on specific aspects of the safety performance monitoring procedure. The guidance was developed based on the findings of the case study applications.

Identifying Projects or Project Elements for Safety Performance Monitoring

Safety performance monitoring begins in the planning and programming stage. First, needs are identified based on considerations of safety, construction cost, operational efficiency, environmental impacts, and various other concerns. Then, projects are authorized based on identified needs and feasibility of improvement. Crash data analysis has historically been used to identify facilities that may need safety improvement. Additional considerations may include funding constraints or earmarking, programming policies, desire to implement complementary improvements simultaneously, or system-wide balancing of improvements (*3*, *4*).

Determining Geographic Limits of Evaluation

During the planning and programming stage, the evaluation should target all facilities that are candidates for possible improvement. The facilities under consideration for improvement should be included in their entirety. However, because detailed data collection does not commence until the preliminary design stage, analyses conducted during the planning and programming stage would be of the basic or basic-EB types described in Table 3-7. That is, analyzed facilities would be described in terms of the "average" or "typical" values for the various design elements. Additionally, representative portions of a facility can be evaluated in lieu of the entire facility.

During the preliminary design stage, the facility to be upgraded should be analyzed in its entirety, in as much detail as possible. This analysis can help identify design elements that could yield reduced crash frequency if improved. Once a preliminary schematic is developed for the upgraded facility, the new design should also be analyzed in its entirety. These analyses should focus on design elements that are set during this stage, such as number of lanes, cross-sectional element widths, driveway counts, curvature, and intersection skew.

During the PS&E stage, analyses should focus on specific segments of the facility that may need to be reevaluated. The need for reevaluation may become apparent when decisions are made on specific design elements that are known to affect safety performance. These design elements may include barrier placement, side slope, horizontal clearance, grade, and turn bay or island channelization presence.

Using Accident Modification Factors

Generally, the combined AMF shows how a given facility's crash frequency compares to that of a similar facility with "base" conditions. Individual AMFs can be used both to describe a given facility's geometry in more specific terms and to estimate the expected change in safety associated with a change in geometry.

In the preliminary design stage, the combined AMF can be used to determine which of the analyzed facilities have potential for safety improvement, while individual AMFs can help guide the selection of geometric improvements at a given facility. Individual AMFs should be used for every design element that is represented in the design.

Using Empirical Bayes Adjustment

In the planning and programming stage, safety evaluations are conducted on a group of existing facilities that are being considered for improvement. If crash data are available for all of the facilities in the group, basic-EB analyses should be conducted on all of the facilities. EB adjustment will provide increased confidence that facilities chosen for improvement do actually rank higher than similar facilities in terms of crash frequency.

EB adjustment can be used any time crash data are available and the facility is not undergoing major physical changes (*5*). "Major physical changes" include, but are not limited to, changes to the number of lanes, major realignment, and changes to the number of intersection legs.

Analyzing Alternatives

Alternatives analysis occurs during the preliminary design stage, after a facility has been chosen for improvement but before detailed design commences. At this stage, alternatives analysis involves quantifying the expected crash frequency for the do-nothing option and each project alternative, and comparing the expected safety benefit for each alternative with its construction cost. When funds must be spent on a specific facility, alternatives should be chosen to maximize net benefit or incremental benefit-cost ratio. When funds are to be allocated among different facilities, projects should be chosen based on benefit-cost ratios.

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APPENDIX: INTERVIEW QUESTIONS

TEXAS DEPARTMENT OF TRANSPORTATION PRACTITIONER INTERVIEW QUESTIONS

1. When in the design process is safety usually evaluated?
    a. Formally, in specific tasks or steps?
    b. Informally, as needed?
    c. Early or late in the process?
2. What is the scope of your safety evaluation procedures?
    a. Entire project?
    b. Specific design element (turn bay, culvert location)?
    c. How are potentially troubling design elements identified?
3. How is safety usually evaluated for projects? Does it vary for 4R and 3R projects?
4. What additional safety requirements must designers consider other than meeting the design standards in the *Texas Roadway Design Manual*?
5. Has your district produced policies to incorporate safety considerations into the design process?
6. There are some recently-developed quantitative safety evaluation tools from TxDOT Research Project 0-4703 (Incorporating Safety into the Highway Design Process) that are mentioned in TxDOT's *Project Development Process Manual* (page 2-33).
    a. Have you or anyone you know used any of the tools?
    b. Which one(s)?
    c. What were the circumstances that led you to consider using these tools?
7. If the answer to the previous question is yes, then. . .
    a. Have you used the Research Project 0-4703 tools in a project that is now complete and open to traffic?
    b. When did the project open to traffic?
    c. Have you conducted a formal evaluation to determine whether crashes have been reduced?
8. Do you have any other tools or information that help you evaluate safety?
9. Do you evaluate safety in the value engineering process?
    a. How?
    b. Are there safety experts present at the value engineering meetings?
10. Do you conduct roadway safety audits?
    a. When in the design process?
    b. For which projects?
11. What is the role of crash data analysis in the prioritization and design of projects? Does it vary for 4R and 3R projects?
12. What additional information or tools would you find useful during the design process to help produce safer designs?

OTHER STATE DEPARTMENT OF TRANSPORTATION PRACTITIONER INTERVIEW QUESTIONS

1. Does your state explicitly consider safety in the design process?
2. If so, in what ways:
    a. Formal step in the design process, or informal evaluation as needed?
    b. Quantitative (crash history and forecasting), or qualitative (engineering judgment of safety expert)?
    c. Focused on specific design elements, or on entire projects?
    d. Other ways?
3. Is safety considered in the design of all projects, or just some?
4. If safety is considered for some projects, how is the need for safety analysis determined?
5. Is safety considered in the ranking or prioritization of projects?
6. Does your state's strategic highway safety plan identify future enhancements to the design process to explicitly consider safety?
7. Does your state conduct roadway safety audits?
8. For which projects or facilities are roadway safety audits conducted (all, exceptionally complex or atypical, only projects that were initiated because of safety concerns)?
9. When conducting safety evaluations. . .
    a. What data are typically used?
    b. Are these data readily available?
    c. Where do you obtain the data?
10. What types of tools do you or would you find useful in the evaluation of safety? (For example, one such tool is the Interactive Highway Safety Design Model.)