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Development of a Highway Safety Manual

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ABSTRACT

This report documents and presents the results of a study to develop an annotated outline, prototype chapter, and work plan for the first edition of the Highway Safety Manual. The purpose of the Highway Safety Manual (HSM) will be to provide the best factual information and tools, in a useful and widely accepted form, to facilitate roadway planning, design, and operational decisions based upon explicit consideration of their safety consequences.

TABLE OF CONTENTS

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DEVELOPMENT OF A HIGHWAY SAFETY MANUAL

SUMMARY

There has been a growing recognition that transportation professionals do not have the needed tools to explicitly consider safety when making decisions related to the planning, design, construction, operations, and maintenance of transportation facilities, notably highways. Several years ago, the need for including highway safety to some degree within the Highway Capacity Manual was raised and discussed within the Transportation Research Board's (TRB's) Highway Capacity Committee. Several TRB committees co-sponsored the activities of a subcommittee, referred to as the Highway Safety Manual Joint Subcommittee (HSM JSC), to address this need. The JSC is undertaking an effort to develop a stand-alone manual that would address highway safety in a manner similar to how highway capacity is addressed within the Highway Capacity Manual. The purpose of the Highway Safety Manual (HSM) will be to provide the best factual information and tools, in a useful and widely accepted form, to facilitate roadway planning, design, and operational decisions based upon explicit consideration of their safety consequences.

The purpose of this study was to develop an annotated outline, prototype chapter, and work plan for the first edition of the Highway Safety Manual. This document reports on the results of those activities.

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CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

There has been a growing recognition that transportation professionals do not have the needed tools to explicitly consider safety when making decisions related to the planning, design, construction, operations, and maintenance of transportation facilities, notably highways. As a sort of grass roots movement, many involved in highway safety research have expressed the belief that transportation professionals have not made sound decisions because they lack the information of the explicit effects on safety. The perception shared by many in the area of highway design has been that an acceptable level of safety is achieved if minimum geometric design standards are met. Unfortunately, crash statistics and forensic investigations have shown that high crash rates, frequencies and severities can occur at locations where geometric conditions meet or even exceed minimum geometric design standards.

There have also been transportation professionals who have not been able to successfully convince decision-makers within their transportation or highway agencies of the need for additional changes in highway projects to enhance safety. The reason is that there had been no definitive source of information about the expected safety effects resulting from these changes. Transportation professionals were left to their own resources to develop and present the argument for safety improvements to decision makers. Frequently, these arguments have been rejected due to perceptions that they have been subjective in nature and not well founded. While safety may indeed be just one of many factors that are considered in making decisions about highways, safety findings have been often misused to support wildly divergent claims in support or defense of specific decisions.

Several years ago, the need for including highway safety to some degree within the Highway Capacity Manual was raised and discussed within the Transportation Research Board's (TRB's) Highway Capacity Committee. Concurrently, efforts were initiated within TRB's Safety Data, Analysis and Evaluation Committee to investigate the possibility and potential of a separate, stand-alone manual that would address highway safety in a manner similar to how highway capacity is addressed within the Highway Capacity Manual. First, an ad hoc task force was established, which grew into a Highway Safety Manual subcommittee within the Safety Data, Analysis and Evaluation Committee. Over the period of approximately six years, several presentations were made at TRB Annual Meetings and the interest grew. Other TRB committees that related to highway safety were quick to recognize the need and co-sponsored the activities of the subcommittee, which began to be called the Highway Safety Manual Joint Subcommittee (HSM JSC).

With concurrence from the NCHRP Panel that provided oversight of this research effort, the HSM JSC took a lead role in directing the work effort and shaping the three major products generated from this research. The JSC effectively were able to work with the Panel and provide technical oversight and extensive review comments throughout the period of performance. It is anticipated that the JSC will continue to provide custodial stewardship of the development of a first edition and subsequent later editions of the Highway Safety Manual.

While the vision of a Highway Safety Manual is still emerging, it is important to note that the content and format of the Highway Safety Manual will evolve over time. Some of the major decisions reached by the JSC for the purposes of this study are likely to be modified and changed during this process.

PROJECT BACKGROUND AND RESEARCH OBJECTIVE

There is a significant opportunity for improving the explicit role of highway safety in making decisions on roadway design and operations. Improved, low-cost technologies have encouraged many state Departments of Transportation and other agencies to develop systems to deliver better safety information. In addition, there has been a parallel advancement in the science of safety impact prediction. Better understanding of the statistical nature of crashes, coupled with new analytical tools, makes it possible to produce more valid estimates of the effect of geometric and operational changes on the frequency and severity of crashes.

The American Association of State Highway and Transportation Officials (AASHTO) has developed a strategic highway safety plan that includes 22 emphasis areas containing a number of countermeasures designed to quickly reduce fatalities on our nation's roads. Two of the initiatives address safety information and management of the highway safety system. A key strategy for these initiatives involves improving safety information systems for better decision support.

Furthermore, the move toward "context sensitive design" approaches has put additional pressure on state and other agencies to develop the means and tools for making design decisions that may involve exceptions to existing criteria. The safety impacts of such decisions should be explicitly considered.

Recent legislative requirements for improving safety data and the use of safety as an explicit criterion in planning and designing transport facilities have created needs within many agencies for improved tools and techniques for safety analysis. Although there have been substantial investments in research and development on highway safety related to the roadway environment [e.g., Federal Highway Administration's (FHWA) program to develop the Interactive Highway Safety Design Model], there is no commonly accepted, fully integrated approach for safety analysis of designs. Hence, safety may not be incorporated in the most effective manner.

In December 1999, a workshop was held, under sponsorship of eight Transportation Research Board (TRB) committees funded by FHWA, for the purpose of determining the need for, nature of, and feasibility of producing a *Highway Safety Manual* (HSM). A group of about 25 researchers and practitioners participated in the workshop and concluded that there was definitely a need for such a technology transfer activity and that work should begin as soon as possible on the development of an HSM. The results of the workshop will be documented in a TRB Research Circular.

The HSM should have similar attributes to the *Highway Capacity Manual*. The purpose of an HSM will be to provide the best factual information and tools, in a useful and widely accepted form, to facilitate roadway planning, design, and operational decisions based upon explicit consideration of their safety consequences.

The objectives of this project were to (1) complete a scoping study that details the effort required to produce the first edition of the *Highway Safety Manual* and (2) develop a prototype chapter that incorporates the analytical procedure that is being developed by the FHWA for safety estimation on rural two-lane highways.

The objectives of this study were accomplished through eleven tasks. These tasks were as follows:

1. Critically review the conceptual framework outlined in the TRB Research Circular, and, based on past research and current practice, develop a detailed outline for the first edition of the Highway Safety Manual.

2. Submit the outline for review by the National Cooperative Highway Research Program (NCHRP) project panel and the TRB Joint Subcommittee on the HSM.

3. Revise the outline, and prepare a detailed work plan for developing the actual HSM. The work plan shall define the available knowledge upon which to base the HSM and the effort required to distill that knowledge into the HSM. It shall also estimate the staffing, time, and other resource requirements necessary to develop the HSM.

4. Identify critical elements for inclusion in a prototype chapter and potential methods for presentation.

5. Prepare a detailed annotated outline of a prototype chapter, defining both technical content and presentation methods.

6. Submit the prototype chapter outline for review by the NCHRP panel and the TRB Joint Subcommittee on the HSM.

7. Based on the results of the review, develop the draft prototype chapter including proposed interactive tools.

8. Submit an interim report documenting the results of Tasks 3 and 7.

9. Meet in Washington, D.C., with the NCHRP panel and the Joint Subcommittee to review the Task 8 interim report approximately 1 month after its submittal.

10. Revise the interim report based on decisions made at the Task 9 meeting.

11. Submit a final report documenting the entire research effort. The final report shall describe how the project was conducted and also incorporate the revised interim report.

This report is intended to satisfy the eleventh task.

SCOPE OF STUDY

The scope of this study was to develop an annotated outline, prototype chapter, and work plan for the first edition of the Highway Safety Manual. Although the scope of the work plan was the creation of a first edition of the HSM, it was drafted in the context that there will be subsequent editions after the first edition. As such, there are some elements included in the work plan that are intended to facilitate the creation of future editions. Similarly, the annotated outline includes some considerations for future editions.

RESEARCH APPROACH

All aspects of this research were conducted by the research team in close cooperation with the Joint Subcommittee (JSC) of the Highway Safety Manual and the seven task groups of the JSC.

The research approach for each of the three main products of this research, the annotated outline, work plan, and prototype chapter, is described in the following sections.

Annotated Outline

Working closely with the JSC, especially the Content Task Group, the research team developed the structure of the annotated outline through an iterative process. The basic structure of the outline was developed by the JSC at the 2001 TRB Annual Meeting. The basic structure includes five parts: Part I – Introduction and Fundamentals, Part II – Knowledge, Part III – Predictive Methods, Part IV – Safety Management of a Roadway System, and Part V – Safety Evaluation.

Together with the Content Task Group, the research team used their knowledge of the state of the practice in many of the subject areas to provide detail to this basic structure. Topics were included in this detailed outline based on the availability of knowledge and the usefulness of the material for the intended audience. This expanded outline was presented to the JSC at the 2002 TRB Annual Meeting for review. It was also submitted to the NCHRP project panel for review.

A detailed literature search was undertaken to identify materials to be annotated to the outline for each of the topic areas identified. Primarily, the following sources were used to identify this literature:

- U.S. Department of Transportation, Bureau of Transportation Statistics and National Transportation Library, and Transportation Research Board, Transportation Research Information Service (TRIS) bibliographic database Version 2.0.
- The TRB Research in Progress Website.
- The Pedestrian and Bicycle Information Center websites.

- FHWA Guidelines for Signalized Intersections, Task A—Critical Review of Literature and Comparison of Risk Levels Associated with Different Treatments at Signalized Intersections, Draft Report, March 2002. [Unpublished document]
- Road Safety Research website, Dr. Ezra Hauer, on-line at http://www.roadsafetyresearch.org
- Citations from the Ministry of Transportation of British Columbia library electronic catalogue. Provided by Melanie Perkins, Transportation Engineering Specialist, Engineering Branch of the Ministry of Transportation of British Columbia.
- Bibliography of the Interim Highway Safety Programs Manual, British Columbia, 1999. Provided by Melanie Perkins, Transportation Engineering Specialist, Engineering Branch of the Ministry of Transportation of British Columbia.

The research team conducted a cursory review of the abstract of each potential item. Items that were included in the annotated outline were based on the relevancy to the subject matter, study design, and timeliness. The research team concentrated on identifying literature that provided quantifiable safety effects, especially for materials for Part II.

The annotated outline was presented to the JSC for review at the 2002 midyear meeting. The JSC identified revisions and then approved the annotated outline based on those revisions. The annotated outline, included as Appendix B, represents the JSC approved annotated outline.

Work Plan

The work plan was developed in close coordination between the research team and the Policy Task Group. The research team was also in close communication with the agencies, namely FHWA and NCHRP/NAS, which will fund the majority of the research that will form the basis of the first edition of the HSM.

The structure of the work plan was modeled after the work plan used by the Highway Capacity Committee to develop the Highway Capacity Manual. One of the main elements of the work plan is the action plan. The action plan identifies and briefly describes the tasks and subtasks necessary to create the first edition. The action plan specifies three types of tasks, categorized by their overall function: preparation tasks, development tasks, and composition and production.

Vital to the schedule for the work plan was the progression of that research, as it is often the time controlling element. The intention of the JSC at the Annual Meeting in 2002 was to produce a first edition of the HSM in five years. Based on a realistic assessment of the likely funding cycle and progression of the research, the delivery date for the first edition of the HSM was changed to December 2007. The schedule was developed accordingly.

Prototype Chapter

Similar to the annotated outline, the prototype chapter was developed in coordination with the Content Task Group. First, the research team identified critical elements for the prototype chapter. After these elements were developed, a draft outline was produced. The resulting prototype chapter was drawn heavily from the rural two-lane accident prediction model that was developed for the Interactive Highway Safety Design Model. This model was used because it represents the best state-of-the-practice in accident prediction. The research team was in periodic contact with FHWA to discuss the progress of the model and worked to develop the prototype chapter in this context.

The prototype chapter was intended to illustrate the content and format of chapters that will be included in Part III of the first edition HSM.

CHAPTER 2

FINDINGS

The findings of this study are documented as three products. These products constitute the appendices as follows:

- Appendix A – Annotated Outline for a First Edition of the Highway Safety Manual
- Appendix B – Work Plan for the Development of a First Edition of the Highway Safety Manual
- Appendix C – Prototype Chapter on Two-Lane Rural Highways

The annotated outline includes the five parts that will constitute the HSM. Part I provides information on the introduction materials and fundamental safety relationships. Part II of the HSM will be the knowledge sections. Topics that will be included in this section are outlined with annotations of relevant literature. Part III of the HSM will constitute the predictive methods chapters. Part IV will provide information on the safety management of a roadway system. Part V will provide information on conducting safety evaluations.

The work plan for the first edition of the Highway Safety Manual (HSM) consists of four elements: an action plan, a level of effort estimate for each of the proposed chapters, a schedule of activities, and an identification of research needs.

The prototype chapter is a prototype of Chapter 8: Rural, Two-Lane Roads. This chapter is intended to be in Part III of the HSM. The prototype chapter is intended to be illustrative of both the content and format of chapters in Part III of the HSM.

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CHAPTER 3

INTERPRETATION, APPRAISAL, AND APPLICATION

The three products of this research are intended to aid in the development of the first edition of the Highway Safety Manual. The first edition HSM is a developing project. As such, the products of this research are evolutionary in nature. For instance, as the state of the research advances, topics may need to be added to the annotated outline to ensure that they are addressed in the HSM. Alternatively, for topics that are already identified in the annotated outline, references to new literature may be added as the research results become available. Additionally, the work plan, by nature, must be flexible to accommodate potential changes in the timeline, funding, or staffing levels needed. The duration of tasks, costs, and level of effort were all estimated based on the best available information. However, these estimates will likely change as the project progresses and more is understood about the needs of each task.

Issues

Many issues will need to be addressed in the preparation of the draft first edition of the HSM and in the development of subsequent editions. These issues are identified and discussed briefly in the following paragraphs. Many of these have been considered and, to a certain degree, addressed during the preparation of the three major products of this research (i.e., the Annotated Outline, Work Plan and Prototype Chapter). However, the development of the HSM is an evolving process and the vision is still very much being shaped and modified. Thus, these issues will continue to present challenges in the years ahead.

Funding. In order to produce the first edition of the HSM, funding is required for the following:

- Conduct of research to develop the procedures and tools for the HSM,
- Composition of other sections and chapters, and
- Production of draft review and final release versions.

The level of effort required to develop the HSM are beyond the limits of what can be reasonably expected from members of a TRB committee, task force or joint subcommittee to provide on a voluntary basis. For the HSM to become a real, living document, additional funding sources need to be identified and funds need to be obligated to this effort. NCHRP approved one major research effort on the development of crash prediction models for urban and suburban arterials. This is the third of three major highway types for which accident prediction methodologies are to be included in the first edition. The first highway type is two-lane rural roads, which is the subject of the prototype chapter presented as Appendix B of this report. The second highway type is multilane, rural highways. As of this report date, the Federal Highway Administration (FHWA) is funding on-going research to develop and refine crash prediction models for both two-lane and multi-lane rural roads. While this level of funding for the initial research efforts may be adequate to continue efforts toward the development of the tools for the first edition, long-term sources of funding are needed to sustain and improve upon the first edition. Specifically, the goal is to produce crash prediction methodologies for other highway facility types including urban divided and undivided streets, urban two-lane streets, urban freeways and expressways, and ultimately rural interstate freeways. Consequently, research will be needed to develop the initial predictive tools similar to those currently being developed for two-lane rural highways, multilane rural highways and urban and suburban arterial highways. This requires dedicated funding. Moreover, after the tools in the first edition of the HSM have been released and users have had the opportunity to apply these tools, then deficiencies and limitations with the procedures will most certainly be identified. This will then necessitate enhancements and improvements to the methodologies, which in turn are likely to spur the need for more research. Hence, continued funding will also be needed to upgrade the predictive methodologies for two-lane rural and multilane highways and urban and suburban arterial highways.

Involvement of Multiple Perspectives. Based on several meetings that have been held, there is a clear need to embrace multiple perspectives during the preparation of this first edition and subsequent editions. Many have offered strong opinions that the document must be sufficiently broad in coverage of topics considered under the highway safety umbrella. The consensus has been that this document should not be written solely for a small group of potential users, such as just highway designers or solely traffic engineers involved in highway projects. This creates a definite problem, however. As the breadth of materials covered by the HSM increases, the scope and size of the document also increase. Thus, it becomes more difficult to produce a meaningful document if it means that the document must be all things to all people involved in highway safety. There are limits as to what can realistically be produced. This is especially true if the concern is to present meaningful information that is well founded and based on empirical studies. The decision made for this project was to sharpen the focus of the first edition of the HSM. Specifically, the objective was to provide the best available information to assist transportation professionals involved in the planning, design, and operations of highways so they could make more informed decisions that explicitly consider safety. Clearly, there are other constituencies in the highway safety community that will expand the HSM to cover topics that are outside the subject matter covered by the first edition. This will be a continual challenge to those involved in the stewardship of the HSM.

By way of another example related to multiple perspectives, it is important to note that there have been significant differences of opinions within the core group of transportation professionals who have become the primary caretakers of the HSM. Even the very name of the manual has been hotly debated. At the California conference in 1999, specifically the title of the document was openly discussed and many favored the title, Roadway Safety Manual, rather than Highway Safety Manual, because of the numerous connotations that are associated with the term highway safety. Many in the traffic enforcement community, driver licensing community, and driver behavior programs are likely to expect that relevant topics related to the driver, vehicle and enforcement will be adequately covered in a Highway Safety Manual. The decision was made that the title should be Highway Safety Manual and the focus of the manual is not on those topics, albeit they are likely to be mentioned briefly in the first edition. However, this is not to mean that all are satisfied and the title will not be a topic for discussion. Involving multiple perspectives will certainly result in substantial improvements to the final document that is produced, but it will also create obstacles for its development.

Criteria for Inclusion of Material in the HSM. The authors of the chapters of the first edition have a daunting task in front of them. They will need to distill a large amount of published and unpublished literature before deciding what should be incorporated into the first edition of the HSM. It is important to note that this issue pertains primarily to the proposed knowledge part of the HSM. There are similar issues that relate to the predictive part of the HSM. It is clear that unambiguous criteria are needed for the authors to decide when a particular bit of knowledge or research finding should be included in the first edition. All authors should receive the same guidelines to decide what quantitative information as well as qualitative information should be included in the first edition.

While it is left to the HSM JSC and subsequent researchers to develop the criteria, it should be recognized that the criteria will change over time. In fact, the criteria should be flexible such that it can become more exacting for future editions. A generalized bit of qualitative knowledge on one topic may be adequate for inclusion in the first edition, simply because it represents the best available and verifiable safety effect of a specific factor, a particular geometric design and/or traffic control practice. However, in later years, predictive models may be developed that effectively utilize an accident modification function for a specific factor, thereby obviating the need to include generalized information in the knowledge chapters. Or, more recent research may become available that allows more stringent criteria to be applied to determine if the generalized bit of qualitative knowledge is still applicable. In either case, the criteria will necessarily change.

Research Protocols/Criteria for Acceptance of Research Findings. This topic generated a significant amount of discussion during the course of this project. Crash predictive models are, by their very nature, limited in terms of their accuracy, reliability, and applicability. The debate rages on whether a particular model is adequate for application or whether its use should be promoted. It was argued that definitive research protocols need to be established now so that they can be properly followed in future research efforts, thereby ensuring that the findings can subsequently be incorporated into future editions of the HSM. The need to establish criteria or procedures for the acceptance of research findings into the predictive models was also identified. For example, how should accident modification functions be updated? What are the conditions that must exist before new research findings should be integrated into or even replace the accident modification functions that are presented in the first edition? The Research Task Group of the HSM JSC has grappled with this issue and identified some initial actions. While the general direction has been identified, there is still much work in this area.

Quantitative vs. Qualitative Information. One of the ultimate goals of the HSM is to provide users with a set of tools that allows them to assess and estimate the safety effects of a particular action, design, strategy or treatment for the widest range of highway facility types and functional classes. Clearly, it is desirable to have a set of tools that consider the effects of a large number of factors or variables and predicts the safety effects in terms of estimated crash experience for a wide range of roadway features and situations. However, currently the predictive procedures have not been developed to a sufficient level of detail. Nor have they been developed for a large number of situations, roadway features or highway types. Thus, there is great value to providing the most detailed information about safety effects even if they cannot be readily converted into factors for a predictive methodology. Many of those involved with the HSM JSC and related organizations have embraced the general concept that there should be a knowledge part in the HSM and that it should contain both quantitative and qualitative knowledge. If the best available information about the safety effect of a specific item is only qualitative in nature, then there have been few objections expressed about including the qualitative information in the HSM. There should be no rush to provide quantitative information about safety effects if the basis for those findings is flawed. Similarly, if the quantitative information is based on a very limited sample or if there are some reasonable concerns about the applicability of that information, then it should not be included in the first edition of the HSM. It is recognized that many users will desire more detailed quantitative knowledge and find qualitative information lacking in its ability to meet their needs. Consequently, the goal should be that, over time, qualitative information is replaced with quantitative knowledge in future editions.

Emerging Safety Effects. The proper consideration of this issue will be a continual need. Those involved in road planning, design, operations and maintenance decisions will continue to express the need for knowledge on the safety effects of emerging technologies, practices and systems. For example, traffic engineers may want to know the safety effects of LED (Light Emitting Diode) signals compared to conventional glass lens for traffic signal displays. Transportation planners may want to know the safety effects of specific traffic calming devices. Highway design engineers may want to know the safety effects of innovative intersection designs, roundabouts, and other novel geometric treatments. In many cases, the knowledge of the safety effects will not be readily available. In fact, it may take a number of years before the empirical evidence is sufficient to draw inferences about the relative safety effects. The question arises as to what information, if any, should be presented in the Manual until the safety effects are adequately quantified. This becomes even more important if the Manual will be updated on a frequent basis or is web-based. The custodians of the HSM will bear the burden for new and improved information on safety effects from the highway safety community. The HSM Task Force discussed the concept of providing a "current topics in safety" service. This service would address emerging safety issues in the interim between versions of the HSM. Materials such as research results or topic syntheses would be identified and distributed. Potential methods of distribution identified included a publicly accessible website or hard copied materials.

Scope of the Document. While this report presents recommendations on a draft annotated outline for the first edition of the HSM and several suggested "placeholders" for future sections and subsections in subsequent editions, the scope of the document may need to be re-defined in the future. There are many situations and examples for which information on safety effects are clearly needed. However, the distinction on whether the situations should be included in scope is far more ambiguous. Consider the tangible example of red light running camera systems, which was raised as an issue in the annotated outline. Are these systems forms of automated enforcement and therefore are not appropriate for the defined first edition of the HSM? Or, are they special treatments instituted at problematic intersections as a safety measure? The distinction was not readily apparent to the authors of this report. Consequently, guidance for both alternatives are presented in the draft annotated outline. There are several other situations for which it is not readily apparent on whether they should be excluded from the HSM, treated in a casual manner, or explicitly discussed in the HSM.

Custodial Role of TRB's HSM Joint Subcommittee. The Highway Safety Manual Joint Subcommittee has clearly seized the initiative and will continue to exercise some degree of custodial stewardship over the HSM. To be a viable document, the consensus opinion of a broad based group was that it should be developed under the sponsorship of the Transportation Research Board/National Academy of Sciences, in a manner similar to the Highway Capacity Manual, which is published as TRB Special Report. The process has been initiated to transform the structure of the Joint Subcommittee to a full-fledged, standing committee that will have, as one of its primary objectives, the production, oversight, and stewardship of the HSM. The purview of this committee has been discussed. Several have recognized that it should not be so narrowly restricted to the development and production of the Manual. Rather, the committee should have some influence over the research on safety effects, especially those that may be incorporated into future editions of the HSM. Clearly, how the HSM JSC evolves over time and the definition of the extent of its purview will have a large bearing on the scope, content, format and substance of future HSM editions. Thus, the role of the HSM JSC will likely be redefined in the years to come.

Endorsement/Acceptance by the Highway Safety Community. This is one of the potentially biggest issues that will need to be considered if the HSM is to achieve its intended objective. It requires a substantial amount of effort and investment. The HSM JSC User Liaison Task Group has taken an excellent first step in conducting a comprehensive survey of potential users and endeavoring to involve others in the development of the HSM. Several of the comments received from that survey, particularly from those involved in transportation planning, were addressed in the development of the final annotated outline. In fact, the outline was revised to incorporate several additional topics identified by the survey respondents. Acceptance and endorsement by potential users warrants further attention. There is a need for more detailed research on desired format and applications. To become a nationally accepted and widely used resource, additional outreach and marketing is needed. Relatively minor investments for marketing activities related to the HSM made at the early stages of the development process will yield benefits when the first edition is ready for release.

Audience. In many of the earlier meetings and conferences, the topic of the intended audience for the HSM was frequently debated. While this report recommends that the first edition of the HSM should be geared toward transportation professionals, including highway geometric design engineers, transportation planners, and traffic engineers, involved in planning, design and operational decisions for roads and highways, it has to be recognized that there are many potential future users. As the development process continues, the issue of audience should be periodically resurfaced and discussed. The goal should be to ensure that the HSM is reaching its primary and secondary targeted populations and the format and content of the HSM are meeting the needs of its users. Considerations should be given to exploring methods to enhance and expand upon the applicability of the content. As noted earlier, the title has connotations that cannot be overlooked. There are valuable lessons to be learned from examining the evolution of the Highway Capacity Manual with respect to the changing audience of users. While capacity was, at first, primarily a traffic operations subject, procedures have been developed and expanded for planning and design. By analogy, the changing needs of the expected users of the HSM need to be assessed and considered in the continuing development of the HSM.

Format for the HSM. The approach taken for this research project was to model the prototype chapter after the current paper-based format used by the Highway Capacity Manual. The draft prototype chapter, which is presented in Appendix C of this report, presents a predictive methodology that could be applied to predict the safety effectiveness for two-lane, rural highways. The predictive procedures were derived from the latest and best available methods under development in the United States. This was a conscious decision to utilize this format and these procedures to serve as an initial trial balloon. The underlying philosophy was that it was important to address the type of content first. Namely, what will the predictive methodology allow a user to do, as opposed to attempting to define the most appropriate format? Clearly, it should not be expected that the prototype chapter as prepared will represent the final content for this chapter in the first edition. There are a number of relevant research projects currently underway that will influence the version that will be included in the first edition. In addition, the format of the draft prototype chapter that is presented in this report may not be the final format. There are numerous advantages to employing other formats, including interactive CDs and web-based formats that can certainly improve upon user friendliness and increase the number of users and appropriate applications of the methodologies and knowledge in the HSM. The determination of the most appropriate medium in which to deliver the first edition of the HSM warrants further discussion and development. The work plan identifies several areas for additional work.

While on the topic of overall format, it is important to recognize that there may need to be differences in format for the chapters to be included in Part II, Knowledge, of the HSM compared to the format in Part III, Predictive Methods, of the HSM. Part II is intended to present the best available information, i.e., knowledge, on the safety effects of a wide variety of items, including roadway features and situations, geometric design elements, traffic control devices, traffic operations strategies, pedestrian and bicycle considerations, among others. For certain situations, the information may be qualitative in nature and represent the best available knowledge about safety effects. For other items, the information may be quantitative. For a few items, the information may be quite detailed and represent an established relationship between crashes and some specific factor in the form of a crash modification function. It should be remembered that the intent of Part II is to cover a broader range of situations and factors than simply those variables that are in the final form of a crash prediction methodology for a specific highway type. In comparison, the material to be contained in Part III, Predictive Methods, should be packaged so that would-be users can easily and properly apply the methods to the appropriate situations. For Part III, it would be more meaningful to utilize a format that ensures consistent application of the methods. Consequently, the format of Part II could differ from the format of Part III, regardless of delivery media. Function should be considered when selecting format.

Evolutionary Nature of the HSM's Predictive Methods Part. On a topic related to the format for the Predictive Methods part of the HSM, it is appropriate to consider that the methods are likely to undergo evolutionary changes in an attempt to improve upon the predictive ability of the method and to expand so that methods can be applied to a greater range of situations found in and on roadways, pedestrian facilities and bicycle facilities. Thus, the documentation should be presented in a manner such that users can fully understand the limitations and applications of the methods. While the methods that are presented in the first edition of the HSM should represent the best available, they should not be sold as the definitive procedures.

Relationship of the HSM to Existing Policies. Various members of the HSM task groups identified the potential for conflicts between materials in the HSM and existing polices, manuals, or standards. The MUTCD and AASHTO's Green Book were cited as examples. Although conflicts with these and other materials could be problematic, the task groups expressed a strong desire to put forward what is appropriate and not be limited from finding the facts. It was suggested that the policy task group want to define a process to manage conflicts as they arise. This process could include a mechanism to identify where conflicts may potentially surface. Coordination with the groups that publish manuals, standards, and existing policies is crucial.

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CHAPTER 4

CONCLUSIONS AND SUGGESTED RESEARCH

The overall conclusion of this effort is that there is a need to conduct the basic research that will be the foundation of the content for the first edition of the Highway Safety Manual. This is especially true for the chapters that comprise Part III of the Manual.

The annotated outline and work plan developed as part of this research and included as Appendix A and B identify suggested research needed to produce the first edition of the highway safety manual. Notably, the work plan includes a section entitled "Research Needs" that identifies needed research.

Additional research areas have been identified by the tasks groups of the JSC. Information on these research areas is available from the JSC.

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APPENDIX A: ANNOTATED OUTLINE FOR A FIRST EDITION OF THE HIGHWAY SAFETY MANUAL

Part I – Introduction and Fundamentals

Part II – Knowledge

Part III – Predictive Methods

Part IV – Safety Management of a Roadway System

Part V – Safety Evaluation

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Table of Contents

List of Tables

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PROPOSED HSM STRUCTURE

Recognizing the desired purpose of the HSM, the NCHRP Project 17-18(4) project team proposes the following overall structure for the first edition of the HSM:

Part I. Introduction and Fundamentals

Part II. Knowledge

Part III. Predictive Methods

It is proposed that Part I present an overview of the HSM and fundamentals on highway safety, including discussions of the purpose, intended audience, scope of the HSM, the organization of the document, and its intended use. Part I should present information on the basic concepts and parameters of highway safety, such as the following topics:

- What is meant by the term highway/roadway safety within the context of this manual.
- How is road safety measured including discussion of the accuracy of crash data and non-crash surrogate measures.
- Concepts for communicating the relationship between crash-based measures of safety and highway features or characteristics. This would include the introduction of common safety performance functions such as crash frequency versus Average Annual Daily Traffic (AADT) flows for different facility types, etc. (By analogy, chapter 2 in the Highway Capacity Manual is devoted to discussions of Traffic Characteristics.)

Part II is proposed to transmit a majority of the best known factual information about the effects of roadway planning, design and operations decisions on safety. We envision this would include information about the safety relationships for design elements, traffic control devices, and traffic operations strategies. In addition, it is proposed that this section present information about the expected safety effect from roadway, roadside, traffic operations and other countermeasures being considered for the full range of highway, intersection and interchange types.

It is proposed that as many of the safety relationships (e.g., a percent change in crash rate, a probability of a crash, etc.) be expressed in terms of crashes as possible (i.e., not surrogates), recognizing that the collective knowledge may not be adequate to express the relationships to crashes. At this point in time, we propose the development of safety performance functions and crash modification factors. Then, applicable crash modification factors can be combined to estimate the combined effect on safety of various actions.

Editor's Note: If available, crashes are the preferred way to express safety relationships. However, we acknowledge that any measure of safety that the JSC adopts can be used if relationships can be found which meet the underlying criteria to be set.

Please note that our vision is not for this part of the HSM to become simply another synthesis of findings from crash-based literature. On the contrary, we would propose that the best available information (as well as knowledge to be gained from research in the near future) be packaged into the most appropriate format that allows it be useful to transportation planners, highway designers, traffic engineers, and other transportation professionals.

It is proposed that Part III include analytical methods and systematic processes. It is proposed that the first edition include the following three chapters:

- Two-Lane Rural Highways
- Multi-Lane Rural Highways
- Urban and Suburban Arterials

There had been a great deal of recent research on developing predictive methods for two-lane rural roads. The prototype chapter to be developed under project 17-18(4) will be the two-lane rural roads chapter. Recent research had been devoted to multilane rural highways. It is recognized that the intensity of recent research effort devoted to urban and suburban arterials had been less than the effort focus on rural highways. However, there were some strong opinions expressed at the mid-year meeting of the JSC that a chapter on urban and suburban arterials should be included in the first edition. The JSC identified urban and suburban arterials as the highest priority area of research needed.

PART I – INTRODUCTION AND FUNDAMENTALS

CHAPTER 1. INTRODUCTION AND OVERVIEW

1.1 PURPOSE

The purpose of the HSM is to provide its users with the best extant factual information and tools in a useful form to facilitate roadway planning, design, operational and maintenance decisions based on explicit considerations of their safety consequences.

> ***Discussion:*** *The original definition adopted at the Irvine meeting did not make explicit reference to roadway planning. Rather, the original phrase was "roadway design and operational decisions." The term "roadway design" can be interpreted narrowly to pertain to solely final geometric design. For most roadway projects, it is rare to jump to geometric design. Rather, there are planning studies, major investment studies, environmental assessments and/or environmental impact statements, and location studies. Right-of-way plans frequently need to be developed and approved before construction plans can be prepared. For many state agencies, there are a host of activities associated with project planning, project development or scoping, and preliminary engineering. To ensure that the full meaning of roadway design is properly communicated, we suggest to replace "roadway design and operational decisions" by "roadway planning, design and operational decisions." The implication of this modification would be to include in the HSM material that would be useful to transportation planners, geometric designers, and traffic engineers.*

1.2 BACKGROUND ON THE NEED FOR HSM

This section would discuss the need for the HSM and describe the background on how the first edition was developed. The Beckman Center meeting in California and efforts of the JSC would be discussed in this section.

1.3 SCOPE OF THE HSM

The scope of the HSM follows from the declaration of purpose and audience. That is, the HSM shall include factual knowledge that is relevant to RPDOM professionals. Accordingly, the first edition of the HSM will not dwell on matters such as driver education, law enforcement, vehicle safety, crash investigation, and other related subjects, which are also important within the broad topic area of highway safety.

> *Editor's Note: This second should present a total process diagram which can be used throughout this chapter and into other part of the manual where appropriate. This diagram could be detailed out for each section.*

1.4 INTENDED AUDIENCE

The intended audience for which the HSM is written is professionals who make road planning, design, operational, and maintenance decisions. This group includes transportation planners, highway geometric designers, and traffic engineers, among others. For the remainder of this annotated outline, the term 'RPDOM professionals' will always refer to professionals who make roadway planning, design and operational decisions.

1.5 INTENDED USE OF THE HSM

> ***Discussion.*** *The purpose of this section is to make it clear that the purpose of this manual is to convey factual information and analytical tools, not to tell anybody what should be done, or whether some standard or practice is or is not appropriate. The distinction between objective safety and perceived safety will be made in Chapter 2.*

This section is important because it declares the intent of the authors of the HSM about how it should and should not be used. As such, it will define the style of the HSM by specifying what statements may be made in the HSM and what statements must not be made.

> ***Discussion:*** *The original title proposed by the Content subcommittee was "application." We see this chapter as a means to discuss the "nature of the HSM." Our fundamental belief is that the interest of society is best served when decisions by RPDOM professionals are explicitly based on the best available knowledge, and that this applies also to roadway planning, design and operational decisions (even when, as is the case in road safety, the best available knowledge is often imprecise).*

> ***Discussion:*** *One of the concerns about the HSM is the potential that information contained in it may be seen to run counter to guidance now provided elsewhere and that it will be used in litigations with ruinous effect. This concern is real and needs to be dealt with.*

> ***Discussion:*** *One thought that could be included here concerns the fact that safety knowledge is continually growing and changing, like any good science. The goal of the HSM is to continually update the safety knowledge and tools in it to include the best available at the current time. By definition, this means that roadway planning, design and operation practices conducted before the manual was developed would not be based on the same level of safety knowledge as if found in the manual, and should not be judged by the current knowledge. In addition, the HSM is designed for a national audience of users, and as such will not contain jurisdiction-specific factors that can affect safety.*

1.6 CONTEXT FOR THE HSM: USE AND MISUSE OF THE MANUAL

This section would discuss the context in which the manual can be used and how it should not be used (i.e., misuse). The discussion would briefly discuss state and local agency processes related to project planning, preliminary engineering, and final design. The discussion would also address state and metropolitan long-range and strategic planning processes and transportation planning efforts. In addition, traffic operational decision-making processes and safety improvement program processes would be discussed. The discussion should lead readers to understand how the first edition can and should be used and provide insights as to how future editions can be integrated into existing processes. This would include a discussion on how each of the RPDOM professionals would use the manual and the various ways that they would apply the tools. For example, planning professionals would likely use the tools proactively as opposed to highway safety engineers who may use the tools reactively to meet an existing need for improvement. This would also include information on the level at which the tools would be applied (e.g., site specific versus system-wide). Conversely, this section should include a discussion on how each of the RPDOM professionals should not use this manual.

This section of the HSM should also clearly describe the relationship of the HSM to the Manual on Uniform Traffic Control Devices (MUTCD). It should discuss that the MUTCD constitutes a National Standard, and that the HSM is effectively a tool to assist RPDOM professionals in making decisions. The author of this section should recognize that conflicts may arise between the MUTCD and the HSM, even though the HSM will not be intentionally developed to be at odds with the MUTCD. The section should also discuss that there may also be conflicts between AASHTO design policies and the HSM. The section should present guidance with respect when these conflicts occur.

In addition to these discussions, it is suggested that the author of this section develop and include a flow chart showing how the HSM could be used within existing highway planning, design, operations and maintenance process. This discussion should include a description of the most common processes typically employed by State and local transportation agencies in developing and implementing transportation modification projects at the planning level, within the project development and design level, at the and at the operations and maintenance level.

This section should also include a discussion on the application of safety effect estimates to local jurisdictions. It should include a discussion of the total highway safety context and the factors that create variations in locations beyond design and operational elements (e.g. law enforcement practices).

Finally, to help preclude the use of the information in the manual as the “only or best” criteria for good roadway system design and maintenance (in, for example, a liability suit), the section should also include a discussion of the fact that safety is one of a set of factors that the engineer or planner must consider in making a transportation-related decision. Other factors include mobility, traffic operations (including delay reduction), construction and maintenance costs, environmental concerns, community esthetic values, and citizen needs and desires. There will usually be “conflicts” between safety and other factors (e.g., safety concerns may lead to wider clearzones free of trees, but community esthetic desires may be for more trees in medians and near the roadway edge). The goal of the manual is to provide the best safety-related information available for use in roadway planning, design, operational and maintenance decisions. It is understood, however, that the final decision will be based on safety plus these other factors.

Safety Management Systems

This section is intended to provide an overview of Safety Management Systems. These topics are covered more extensively in Part IV. Part IV will be drawn largely from FHWA's Comprehensive Highway Safety Improvement Model (CHSIM) project which will develop tools for safety management. The tools are expected to assist transportation professionals in the tasks related to traditional highway safety improvement programs. It is proposed that this section will provide a concise summary of these topics and refer the interested reader to Part IV of the Manual.

Editor's Note #1: The Federal Highway Administration has taken a leadership role in developing a Comprehensive Highway Safety Improvement Model). A research effort is currently underway. The results of this research are intended to assist States and localities in improving their decision making processes through the use of a new set of analytical tools designed for allocating resources to achieve greater safety improvements. The project will consist of a set of analytical tools designed to:

- *Identify "sites with promise"(roadway sections and intersections) which hold promise for crash reduction.*
- *Diagnose safety problems at specific sites.*
- *Select effective candidate countermeasures.*
- *Develop an economic appraisal.*
- *Develop a priority ranking system.*

The complete package is expected to be developed over a 5-year period and will ultimately be available as a software product for use by States and localities.

Editor's Note #2: Given our interpretation of suggestions made by the Joint Subcommittee Chair, we have not included information on road safety audits in this version of the HSM. Road safety audits have been well documented in a variety of reports including:

- *"Implementing Road Safety Audits in North America. An Informational Report," Institute of Transportation Engineers, 2001.*

- *"PennDOT's Road Test of the Road Safety Audit Process", Pieples, T.R., 1999.*
- *"Road Safety Audit", Austroads, 1994.*

Editor's Note #3: The author(s) of this section are directed to the PIARC Road Safety Manual as a reference for this section. The manual is scheduled for publication in 2002. For more information on the status of the manual, the author(s) is directed to PIARC's website at www.piarc.org.

Highway Improvement Process

It is suggested that this subsection describe, in a general way, the highway improvement process. This should include a diagram of the basic process, and make reference to the fact that it will be covered in much greater detailed in Part IV of the HSM.

This section should provide a brief overview of the highway improvement process including planning, project selection, funding, design, and implementation. It should provide a context for the Highway Improvement Process in the Safety Management of a System (previous section). This section is only intended as an overview. Aspects of the highway improvement process are to be covered in more detail throughout Part IV of the manual.

This section should refer interested readers to other publications that provide detailed information on the process.

Editor's Note: The author(s) of this section are directed to the PIARC Road Safety Manual as a reference for this section. The manual is scheduled for publication in 2002. For more information on the status of the manual, the author(s) is directed to PIARC's website at www.piarc.org.

Context Sensitive Design

The section will provide an overview of context sensitive design. It should briefly describe how context text design affects RPDOM professionals and how one application of the HSM could be for context-sensitive design. It should refer readers to other publications that provide more detailed information on the process.

Editor's Note #1: The author(s) of this section should familiarize themselves with the FHWA and AASHTO website, "Context Sensitive Design/Thinking Beyond the Pavement". The JSC should consider providing dynamic links to the information on this website, depending on the format of the HSM.

Editor's Note #2: The author(s) of this section are directed to the PIARC Road Safety Manual as a reference for this section. The manual is scheduled for publication in 2002. For more information on the status of *the manual, the author(s) is directed to PIARC's website at www.piarc.org.*

1.7 NATURE OF THE HSM

This section would focus on describing the evolutionary nature of the HSM. It would explain how subsequent research will improve upon the relationships and lead to better predictive methods. It also would compare future development of the HSM to the historical development and refinement of the Highway Capacity Manual.

1.8 ORGANIZATION OF HSM

This section would discuss how the remainder of the HSM is organized.

CHAPTER 2. FUNDAMENTALS

It is proposed that the Chapter 2 provide information on common elements and additional knowledge needed for accurate understanding and proper application of the methods and procedures in the HSM.

> *Editor's Note: As opposed to subsequent sections, we have not endeavored to identify literature for Chapter 2. We expect that the author(s) of Chapter 2 would have adequate knowledge to draw upon to complete this section.*
>
> *Editor's Note: The author of this chapter should be aware of concerns associated with designing to minimum standards only and blind adherence to standards. The author should include a discussion that designing to minimum standards will not necessarily mean that a minimum level of safety is the result.*

2.1 WHAT IS SAFETY?

In this section, it is proposed that road safety should be clearly and unambiguously defined. In our opinion, road safety is an expected value that is not to be confused with the count of motor vehicle traffic crashes and/or crashes. A distinction should be made between and among objective safety, perceived safety and nominal safety, as well as the relationships among them.

This section will also discuss the "anatomy of a crash". Information should be provided on the relationship between elements of a crash. Tools to systematically identify all options to available to reduce injuries such as the Haddon matrix and Stan Baker's (Traffic Accident Manual from Northwestern) model of a crash should be presented. This section should include a discussion of the difference between contributing factors and the cause of a crash.

This section should also discuss the attributes of a crash (e.g., contributing circumstances, driver attributes, vehicle attributes, environmental conditions, etc.). This could be accomplished by providing a crash taxonomy. Potential references for this section include Stan Baker's *Causes and Contributing Factors in Traffic Accidents,* ANSI D20-1998 *Data Element Dictionary for Traffic Records Systems,* and ANSI D16.1-1996 *Manual on Classification of Motor Vehicle Traffic Accidents.*

> ***Discussion:*** *One of the major issues to be resolved will be terminology with respect to either motor vehicle traffic accident (as embraced by ANSI) or crash, which has been advocated by NHTSA and other branches of the U.S. Department of Transportation.*
>
> ***Editor's Note:*** *In order to facilitate the explanation of the relationship between expected value and crash counts to the readers, the chair of the JSC suggests that the author(s) of this section use numeric illustrative examples. The extensive use of sample calculations can help, if they are carried beyond the raw results to include interpretations and presentation of results in forms that can be exemplary of what might be used in a public forum.*

2.2 HOW ROAD SAFETY IS MEASURED

Since road safety is defined as an expected value, the measurement of road safety means statistical estimation based on counts of crashes, rather than the counts themselves. It is proposed that this chapter should therefore include discussions on how counts of crashes are obtained and how these are used to estimate safety, including their use in safety prediction methods.

We propose that this section include two safety performance functions (i.e., graphs showing how crash frequency depends on traffic). One function should pertain to a road segment. The other should pertain to an intersection. Using these functions, the concept of crash rate should be defined. A discussion of the use of rates versus frequency should be included. Discussion should be provided that crash rates depend on traffic, which should lead into a discussion of exposure.

Crash Counts

This section should include adequate discussion of what constitutes a motor vehicle traffic crash. It should include discussion of what makes it reportable and what proportion is reported. This section should also include a discussion of the quality of crash counts and the quality of some of the elements that are recorded from a crash. It should identify some of the potential problems including credibility of self-reported information, location accuracy, interpretation errors, etc. It should identify all of the aspects of crash data analysis where potential problems could arise including the crash reporting process, data entry and storage, access and information production, and use of data in analysis. The relationship between data quality and the crash severity should be addressed (i.e., reports of fatal crashes tend to have higher quality data than property-damage-only crashes).

Estimation Accuracy

This section of the chapter should discuss the relationship between the number of crashes counted and the precision with which safety is estimated. On this basis, guidance should be given on how much data are needed to perform common tasks.

Supplementary Data

Crash data are often used in the context of other data such as volume data, roadway inventory data, operational data, maintenance records etc. This section should identify the data sources and methods in which they are used in safety activities.

Indirect Measurement of Safety (Surrogates)

When crash counts are not available (perhaps because the system is not yet in service or has only been in service for a short duration) or when crash counts are too few, safety cannot be estimated from crash counts. In such cases, one must rely on indirect measures such as traffic conflicts. The relationship between direct and indirect safety measurements should also be discussed. This section should therefore include adequate discussion of surrogate measures for crash counts.

Assigning Values to Crashes for Prioritization

When it comes to decisions about where to spend money as part of transportation investments/roadway improvements, the topic of relative values to crashes of different severity needs to be presented and understood. In some analyses, the crashes may be disaggregated by type or severity. Decisions about the amount of money to be spent may require monetary equivalents to be assigned to crashes. It is proposed that this section describe the main methods by which estimates of value are obtained and provide a table of values now in use in various jurisdictions.

This section should also contain a discussion on comparing between agencies. Because of variations in crash reporting practices between agencies, differences will exist in the analysis when making comparisons.

2.3 SAFETY PERFORMANCE FUNCTIONS AND CRASH MODIFICATION FACTORS

In this section, the safety performance of common road and intersection types should be described. The discussion should also focus on how common road and intersection types affect safety and how this effect can be captured.

Common Safety Performance Functions

Desirably, Part III of the HSM will present much of the best factual information about the safety effects of roadway planning, design, and operations decisions in the form of safety performance functions. Thus, it is desirable to introduce the reader to this the most common safety performance functions. This section should include plots showing the relationship between crash frequency and AADT for two-lane, four-lane (divided and undivided), freeways (perhaps by number of lanes), three and four-legged intersections (stop controlled and signalized) in urban and rural settings for several states. By analogy, Chapter 2 of the Highway Capacity Manual introduces the reader to traffic flow concepts and presents many of the basic traffic flow relationships in the form of graphs and charts. We believe that this chapter should perform the same function in an attempt to further educate the HSM user.

How Crash Modification Factors are Obtained

The section should describe the distinction between various methodologies such as cross-section studies and before-after studies that are used to obtain crash modification factors. This material should be provided as a source of information. The strengths and weaknesses of various methodologies should be discussed and some information about common pitfalls (single variable tabulations, regression-to-mean etc.) should be given. This section should also provide information on the strengths and weaknesses of studies that attempt to identify the crash modification from combined treatments (e.g., application of shoulder rumble strips along with chevrons at a hazardous curve).

Traffic "Exposure", Traffic Mix and Demand Management

This section should provide an overview on the relationship between traffic mix and safety. It should include a discussion of all transportation system users (e.g., pedestrians, motorists, heavy vehicles, transit vehicles, bicyclists, etc.) and how accommodating their needs on the same facility may affect safety. For example, the turning radii needed by heavy vehicles has an impact on pedestrian safety. This section should not identify the specific safety effect, but instead introduce discussion on the topics.

This section also should provide a discussion of demand management, its affect on volume, and how this affect relates to safety. Demand management is used to eliminate or shift trips, either from one facility to another or from one mode to another. This in turn alters the volume of a facility. There is a relationship, although not necessarily a linear relationship, between volume and safety. This section should provide a discussion of these topics.

This section should provide an overview on the relationship between traffic mix and safety. It should include a discussion of all transportation system users (e.g., pedestrians, motorists, heavy vehicles, transit vehicles, bicyclists, etc.) and how accommodating their needs on the same facility may affect safety. For example, the turning radii needed by heavy vehicles has an impact on pedestrian safety. This section should not identify the specific safety effect, but instead introduce discussion on the topics.

2.4 HUMAN FACTORS IN ROAD SAFETY

> *Editor's Note: This section is not meant to replicate the comprehensive document that is expected to be produced by another TRB joint committee effort. It should only serve to provide an overview of major topics and concepts so the reader can gain insights into the driving task and its relationship to safety. The reader will be referred to the final draft of that human factors manual. The remainder of this text in this section (2.4) was prepared by Ezra Hauer after consultation with Allison Smiley.*

It is recognized that there are several other documents that have addressed this topic. There are also efforts underway to develop a Human Factors Handbook. The proposed inclusion of this chapter is not meant to imply that the HSM should be all-inclusive in attempting to deal with all human factors topics relevant to highway safety. Rather, it is proposed to provide a much needed overview of human factors.

Driver Characteristics

Within this section, the topic of how driver visual limitations affect the conduct of the driving task should be discussed. Topics should include central and peripheral vision, acuity, contrast sensitivity, conspicuity, and night vision. Furthermore, a discussion of how drivers act as an information processor should be included. Attention, visual search, driver workloads, and perception-reaction time should be discussed. This section could include discussions on how drivers adapt by arousal, their choice of speed, and the expectations they develop about the road and the traffic ahead. In addition, information should be presented on what characteristics are affected by aging and by drugs such as alcohol.

Positive Guidance

In this section, the issues regarding driver response to highway design and traffic control devices should be discussed, as well as methods to improve the information system along the roadway should be described. This section should include topics such as driver expectancy, information processing overload, principles of information shedding, spreading, etc.

Design Consistency

An important consideration in the interest of safety is design consistency. This section should include information on the effect of design consistency in alignment on safety. A state of the art review on highway geometric design consistency by Gibreel, Easa, Hassan, and El-Dimeery (Journal of Transportation Engineering, July/August 1999) will serve as a good source of references for this section.

> ***Editor's Note****: This section on design consistency was added as a separate section in response to a reviewer's comment. However, it can be moved to section 2.4, Human Factors, at the discretion of the JSC.*

2.5 SPEED AND SAFETY

Speed is one of the main factors affecting crash severity. This section should describe what is known about this relationship. Shinar's review in the TRB Special Report 254, Managing Speed, (TRB, 1998) will serve as a good source of information.

Unquestionably, there is a clear link between speed and severity. However, the relationship between speed and crash frequency is not well established. This is how drivers react to changing conditions. Since the relationship or lack thereof is not commonly misunderstood, discussion of this topic should be included in the HSM.

This section should address topics such as: the contribution of speed as a causal factor for collision (e.g., perception/reaction time impacts, run off road at ramps and curves, truck rollovers on ramps/curves, left turn collisions, rear-end collisions), human factors considerations with respect to speed, and speed perceptions.

> ***Editor's Note****: Speed as a fundamental variable was questioned by some members of the JSC. For now it is included as a fundamental variable. The decision to include or remove it is for the JSC to decide upon.*

2.6 SAFETY EVALUATION

This section of the HSM is intend to assist RPDOM professionals so that they can be better able to critically assess published results, to understand what data are needed to account for the most important factors and to determine how much of it is needed to attain a specified precision. The contractor believes that RPDOM professionals should not be encouraged to engage in estimation of safety effect because to do so requires expertise they seldom possess. The subtopics proposed for this section include the needs identification for system improvements, data requirements for evaluations, a basis for comparison, the significance of results and program evaluation. The contractor also wishes to point out that, in their initial HSM outline, the HSM Content Subcommittee's had originally proposed the estimation of the safety effect of certain highway improvements and the estimation of the safety effect of an entire program of perhaps diverse improvements that form a safety enhancement program.

PART II – KNOWLEDGE

Literature for Part II was identified through a variety of sources. The following sources should be acknowledged:

- U.S. Department of Transportation, Bureau of Transportation Statistics and National Transportation Library, and Transportation Research Board, TRIS Online Version 2.0.
- FHWA Guidelines for Signalized Intersections, Task A—Critical Review of Literature and Comparison of Risk Levels Associated with Different Treatments at Signalized Intersections, Draft Report, March 2002. [Unpublished document]
- Road Safety Research website, Dr. Ezra Hauer, on-line at http://www.roadsafetyresearch.org
- Citations from the Ministry of Transportation of British Columbia library electronic catalogue. Provided by Melanie Perkins, Transportation Engineering Specialist, Engineering Branch of the Ministry of Transportation of British Columbia.
- Bibliography of the Interim Highway Safety Programs Manual, British Columbia, 1999. Provided by Melanie Perkins, Transportation Engineering Specialist, Engineering Branch of the Ministry of Transportation of British Columbia.

Throughout this part of the HSM, discussions of interactions between and among factors should be identified and fully discussed. Alternatively, the author may want to consider the including the advantages and disadvantages of dealing with the interactions explicitly or within the subsections that may be perceived to be directed to a single topic, design element, traffic control feature, or other element. This should also be in the back of the authors' minds when they develop this section.

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CHAPTER 3. ROADWAY SEGMENTS

It is proposed that the Chapter 3 provide information on safety effects of various design elements, traffic control devices, and operational elements on roadway segments. This chapter will also address the safety of pedestrians and bicyclists on roadway segments. In addition, non-recurring congestion, and its effect on safety, should also be discussed with the chapter.

3.1 SAFETY EFFECTS OF HIGHWAY DESIGN ELEMENTS

This section will provide information on the safety effect of highway design elements on highway segments.

> *Editor's Note: The author of this section should familiarize himself/herself with the Roadside Safety Analysis Program (RSAP), recently developed as part of NCHRP project 22-9. RSAP can test the effectiveness of the various countermeasures that are used to reduce the severity of single-vehicle crashes on a highway facility. They should also familiarize themselves with NCHRP Synthesis of Highway Practice 299: Recent Geometric Design Research for Improved Safety and Operations.*

Cross Section Elements

Information on the safety effects of cross-sectional design elements of roadway segments will be developed as part of the research for Part III of the HSM and inserted in this location of the HSM. These chapters are expected to include rural two-lane highways, rural multilane highways, and urban and suburban arterials. The urban and suburban arterials chapter will call for research results that are currently being developed in NCHRP Project 17-26, Development of Models for Prediction of Expected Safety Performance for Urban and Suburban Arterials. If the research is completed in time, the knowledge will be used here.

Only those pieces of knowledge that were included in the analytical chapters should be included here, unless there are additional variables which could not be included in the models, about which some knowledge base can still be provided.

The reader will be directed to the FHWA publication, "Safety Effectiveness of Highway Design Elements. Volume III: Cross Sections".

Traveled Way: Lane Width and Number of Lanes

This subsection will provide information on the safety effects of increasing or decreasing the width of the travel lane. It will also include information on the safety effect of adding a lane or taking a lane away from the traveled way. This will include information on using the shoulder width or part of the shoulder width to provide an additional lane to the traveled way.

Research on rural two-lane highways for Part III of the HSM addressed the relationship between lane width and safety as reported in *Prediction of the Expected Safety*

Performance of Rural Two-Lane Highways. Generally, as the lane width increases, the crash risk decreases. The relationship is defined differently depending on the average daily traffic volume with the crash risk generally increasing for most lane widths as volume increases.

Similar information on rural multilane highways and suburban and urban arterials will be developed and inserted in this location upon the completion of the research. Potential resources that identify the relationship between lane width and number of lanes and safety will on urban and suburban arterials are described in

Table A- 1.

Shoulders: Shoulder Width and Type

Research on rural two-lane highways for Part III of the HSM addressed the relationship between lane width and safety based on research reported in *Prediction of the Expected Safety Performance of Rural Two-Lane Highways*. Generally, as the lane width increases, the crash risk decreases. The relationship is defined differently depending on the average daily traffic volume with the crash risk generally increasing for most lane widths as volume increases.

Additionally, this subsection will include any information on the safety effects of shoulder width and shoulder type on rural multilane and urban and suburban arterials developed for Part III of the HSM. *Table A- 2* identifies some potential resources on the relationship between shoulder width and type and safety on urban and suburban arterials.

Curbs

Information on the safety effects of using curbs on the outside of roadway segments will be addressed in this subsection. Both barrier and mountable curbs will be covered. The relationship between crashes on curb roadway segments will be compared to similar roadway segments without curbs. The use of curbs in the median will be covered in the next subsection. *Table A- 3* contains some potential resources for this section.

Medians

Information on the safety effects of using various median types versus not using a median on roadway segments will be provided in this subsection. If a median is used on roadway segment, the width of the median affects the safety performance. This subsection will identify the safety benefits of various median widths. The relationship between crashes and other cross-sectional elements of highway medians (e.g. slope) will also be identified in this subsection.

Relevant information on the safety effect of medians developed during the research for the Analytic Model Chapters on rural multilane highways and suburban and urban arterials will be inserted in this location upon the completion of the research. Table A- 4 *identifies some potential resources on the relationship between medians and safety on urban and suburban arterials.*

Editor's Note: The author should also include a cross-reference in this section to Section 7.1, Access Management, because of the use of medians in access management strategies.

Table A- 1: Potential resources that identify the relationship between lane width and number of lanes and safety on urban and suburban arterials.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
Accessed March, 2002	"Lane Width and Safety", Unpublished Literature Review by Dr. Ezra Hauer, located at www.roadsafetyresearch.org	Critical review of literature on the safety effects of lane width	Comprehensive, critical review of lane width and safety
1995	Curren, "Use of Shoulders and Narrow Lanes to Increase Freeway Capacity", NCHRP Report 369	Analyzed crash data to determine the effect on safety of using shoulders with or without narrows lanes to increase freeway capacity; safety evaluation was conducted on five corridors	Potential resource
1995	Hadi et al., "Estimating Safety Effects of Cross-Section Design for Various Highway Types Using Negative Binomial Regression"	Analyzed FL crash data to estimate the effect of cross-section design elements (including lane width) on the safety of urban highways	Identified by Hauer, potential resource, limited to FL data
1990	Harwood, "Effective Utilization of Street Width on Urban Arterials", NCHRP Report 330	Evaluated the safety effect of reallocating urban arterial street width to create more lanes; 35 improvement projects	Identified by Hauer, potential resource
1987	Urbanik and Bonilla, "Safety and Operational Evaluation of Shoulders on Urban Freeways"	Summarizes past studies	Identifies potential resources
1980	McCasland et al., "Freeway Modifications to Increase Traffic Flow"	Summarizes safety experiences, from past projects from various states that increased lanes	Potential resource

Table A- 2: Potential resources on the relationship between shoulder width and type and safety on urban and suburban arterials.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
Accessed March, 2002	"Shoulder width, Shoulder Paving, and Safety", Unpublished Literature Review by Dr. Ezra Hauer, located at www.roadsafetyresearch.org	Critical review of literature on the safety effects of shoulders	Comprehensive, critical review of shoulders and safety
2001	Strathman et al., "Analysis of Design Attributes and Crashes on the Oregon Highway System"	Used crash data to investigate the relationship between roadway design attributes (including shoulder width) and crashes; Oregon state highway system; identified relationship potentially unique to urban	Potential resource although limited to OR and not targeted at shoulders
1995	Hadi et al., "Estimating Safety Effects of Cross-Section Design for Various Highway Types Using Negative Binomial Regression"	Used FL crash data to investigate the relationship between roadway design attributes (including shoulder width) and crashes; identified relationships unique to urban roadways	Identified and reviewed by Hauer, potential resource
1986	Harwood, "Multilane Design Alternatives for Improving Suburban Highways."	Studied the effect of cross-section design elements (including shoulders) on crashes on suburban highways, used CA and MI data	Identified and reviewed by Hauer, potential resource

Table A- 3: Potential references on the relationship between curbs and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1996	Lienau, "Safety Effects of Barrier Curb on High-Speed Suburban Multilane Highways"	Used crash data in a before and after matched comparison study to evaluate the effect of barrier curb on safety; high-speed suburban multilane highways; sites in TX and IL	Potential resource
1995	Fambro et al., "Geometric Design Guidelines for Suburban High-Speed Curb and Gutter Roadways"	Used crash data to evaluate the safety effect of high-speed curb and gutter roadway sections in TX	Potential resource, limited to TX

Table A- 4: Potential resources on the relationship between medians and safety on urban and suburban arterials.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
Accessed March, 2002	"The Median and Safety", Unpublished Literature Review by Dr. Ezra Hauer, www.roadsafetyresearch.org	Critical review of literature on the safety effects of medians	Comprehensive, critical review of medians and safety
1998	Castronovo et al., "Investigation of the Effectiveness of Boulevard Roadways"	Used boulevards in Michigan to compare the crash rate of roadway with continuous center left-turn lanes to boulevards	Potential resource
1995	Elvik, "The Safety Value of Guardrails and Crash Cushions: A Meta-Analysis of Evidence from Evaluation Studies"	Meta-analysis of 32 studies that evaluated the safety effect of median barriers (and guardrails and impact attenuators)	Potential resource
1995	Hadi et al., "Estimating Safety Effects of Cross-Section Design for Various Highway Types Using Negative Binomial Regression"	Analyzed FL crash data to estimate the effect of cross-section elements (including median width and type) on the safety of urban highways	Identified by Hauer Potential resource, limited to FL data
1994	Bowman and Vecellio, "Effects of Urban and Suburban Median Types on Both Vehicular and Pedestrian Safety"	Evaluated the safety effect of various medians on vehicular and pedestrian safety; analyzed over 30,000 crashes; 3 cities	Potential resource
1993	Long et al, "Safety Impacts of Selected Median and Access Design Features"	Cross-sectional eval. of effect of median on crashes on urban arterials; various of medians, no medians, restrictive medians; 400 miles of urban roads in FL	Potential resource; limited to FL

Two-way Left-turn Lanes

This section will provide information on the safety effects of using two-way left-turn lanes on roadway segments. Research on rural two-lane highways for Part III of the HSM addressed the relationship between two-way left-turn lanes and safety based as reported in *Prediction of the Expected Safety Performance of Rural Two-Lane Highways*. The presence of two-way left-turn lanes is accounted for in the model through the use of a crash modification factor based on the density of driveways on the roadway segment. As the density of driveways in a section increases, the crash risk increases.

Upon completion of the research, relevant information on the safety effects of using two-way left-turn lanes on rural multilane highways and urban and suburban arterials developed as part of the research for Part III of the HSM will be inserted in this location. Table A- 5 presents some potential resources on the relationship between two-way left-turn lanes and safety on urban and suburban arterials.

Passing Lanes/Short Four-Lane Sections on Two-Lane Highways

The subsection will include information on the effect of including passing lanes on the crash risk of roadways segments. This subsection will also address the considerations of a network approach to the provision of passing opportunities and the impacts of access points on passing lane sections.

Information on the safety effects of the use of short four-lane sections as passing lanes for rural two-lane highways developed as part of the research for Part III of the HSM will be inserted in this location. Research on rural two-lane highways for Part III addressed the relationship passing lanes/short four-lane sections and safety as reported in *Prediction of the Expected Safety Performance of Rural Two-Lane Highways*. In the rural two-lane segment base model, the nominal condition is without passing lanes. The presence of passing lanes, climbing lanes, or short four-lane sections is accounted for in a crash modification factor. They reduce the crash risk, the magnitude of which depends if they are provided in one direction or both. A potential resource, not included in the rural two-lane report, is provided the 1989 ADI Limited report, “Passing Maneuvers and Passing Lanes: Design, Operational and Safety Evaluations”.

Table A- 5:Potential resources on the relationship between two-way left-turn lanes and safety on urban and suburban arterials.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1997	Bonneson and McCoy, "Effect of Median Treatment on Urban Arterial Safety: An Accident Prediction Model"	Used crash data to model the relationship between crashes and median treatment including two-way left-turn lanes on urban arterials	Potential resource
1986	Harwood, "Multilane Design Alternatives for Improving Suburban Highways", NCHRP Report 282:	Studied the effect of cross-section design elements including TWLTL on crashes on suburban highways, used CA and MI data	Identified and reviewed by Hauer, potential resource

Roadside Features and Elements

This section should also include coverage of roadside slopes, median slopes, ditches, and other specific roadside elements and their effects on safety. To minimize duplication, the reader should be referred to the AASHTO Roadside Design Guide, where appropriate.

Information on the safety effects of roadside features and roadside design elements of highway segments for rural two-lane and multi-lane highways will be developed as part of the research for Part III and inserted in this location of the HSM.

> *Editor's Note*: *Recent research efforts have investigated the relationship between roadside features and safety. These research efforts include but are not limited to the following:*
>
> > *Zegeer et al., "Safety Effects of Cross-Section Design for Two-Lane Roads—Volumes I and II"*
> >
> > *Allaire et al., "Relationship Between Side Slope Conditions and Collision Records in Washington State. Final Report."*
> >
> > *Lee and Mannering, "Analysis of Roadside Accident Frequency and Severity and Roadside Safety Management"*
>
> *The author of this section should familiarize himself/herself with this material before drafting this chapter. Additionally, they should familiarize themselves with AASHTO's Roadside Design Guide which is based on an encroachment model which is currently being refined at TTI.*
>
> *Editor's Note: This section includes both a subsection on the Roadside Safety Analysis Program (RSAP) and Roadside Hazard Rating (RHR) as methods for evaluating the safety of a roadside improvement.*

Roadside Safety Analysis Program

The Roadside Safety Analysis Program (RSAP) is used to evaluate the effect of various countermeasures on the safety of a roadside.

Roadside Hazard

According to AASHTO, the term "clear zone" is used to designate the unobstructed, relatively flat area provided beyond the edge of the traveled way for the recovery of errant vehicles. The AASHTO Roadside Design Guide discusses clear zone widths as related to speed, volume, and embankment slope. The rural two-lane model developed for the corresponding analytical methods chapter (Part III) uses roadside hazard ratings to classify the roadside based on the research for Prediction of the Expected Safety Performance of Rural Two-Lane Highways. The roadside hazard rating system not only considers the clear zone but also the roadside sideslope, roadside surface roughness, recoverability of the roadside, and other elements beyond the clear zone such as guardrail or trees. As the roadside hazard rating increases, the crash risk increases. This section will provide information on the relationship between roadside design elements and safety in the context of the roadside hazard rating.

Guardrails and Barriers

This subsection will provide information on the safety effect of using guardrails and other barriers on the roadside and in the median. This subsection will identify the relationship between the crash risk on roadway segments with guardrails and barriers to similar roadway segments without guardrails or barriers. It will also identify the relationship between the crash risk on roadway segments with guardrails or barriers to similar roadway segments with different types of guardrails or barriers.

This subsection will also provide information on the safety effect of guardrail and barrier end treatments used on roadway segments. The relationship between the crashes on similar roadway segments that employ different end treatments will be identified.

Table A- 6 presents potential resources on the relationship between guardrails and barriers and safety.

Table A- 6: Potential resources on the relationship between guardrails and barriers and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
Pending	"Performance of Roadside Barriers", NCHRP 22-13	In-service safety performance evaluation of common guardrails and guardrail terminals used in the US; used NC, IA, and CT data; draft final report is currently available from NCHRP	Potential resource
Accessed March, 2002	"The Median and Safety", Unpublished Literature Review by Dr. Ezra Hauer, located at www.roadsafetyresearch.org	Section 6.5 and 6.6 of this critical review of literature addresses the use of guardrail as a median barrier	Critical review of guardrails used as median barriers and safety
2001	Hunter et al., "Three-Strand Cable Median Barrier in North Carolina: In-Service Evaluation"	Used crash data to evaluate the effect of the installation of cable median barrier on crash rates in NC; only used Interstate locations	Potential resource, limited to Interstates in NC
2000	Ray, "Safety Effectiveness of Upgrading Guardrail Terminals to *NCHRP Report 350* Standards"	Reviews previous in-service evaluations of the safety effect of guardrail terminals	Identifies potential resources
1995	Elvik, "The Safety Value of Guardrails and Crash Cushions: A Meta-Analysis of Evidence from Evaluation Studies"	Meta-analysis of 32 studies that evaluated the safety effect of guardrails along the edge of the road and impact attenuators	Potential resource

Alignment Elements

The reader will be directed to the FHWA publications, "Safety Effectiveness of Highway Design Elements. Volume II: Alignment" and "Safety Improvements on Horizontal Curves for Two-Lane Roads".

Horizontal Alignment

This subsection will include information on the safety effects of horizontal alignment and horizontal sight distance. The safety effects of horizontal design elements such as tangents, curves, superelevation, and spirals should be addressed.

Research on rural two-lane highways for the corresponding Analytical Methods Chapter in Part III of the HSM identified the relationship between horizontal alignment and safety as reported in *Prediction of the Expected Safety Performance of Rural Two-Lane Highways*. In the base model, curves in roadway segments were included based on their degree of curvature with a tangent roadway section as the nominal condition. This was modified using two crash modification functions. The first crash modification function accounts for the length and radius of curves, and the presence or absence of spiral transitions. Generally, crash risk decreases with longer radii, longer lengths of horizontal curves, and the presence of spirals. The second crash modification function accounts for the superelevation. It is based on the superelevation deficiency of a horizontal curve (i.e., the difference between the actual superelevation and the superelevation required by AASHTO policy).

Relevant information on the effect of horizontal alignment on safety developed during the research for rural multilane highways and suburban and urban arterials Analytical Methods Chapters (Part III) will be reviewed and considered for inclusion in this location of the HSM upon the completion of the research.

Vertical Alignment

This subsection will include information on the effect on the crash risk of roadway segments from changes in vertical alignment and the accompanying effect on sight distance. This will include the effect of both up and downgrades, sag vertical curves, and crest vertical curves.

Research on rural two-lane highways for the corresponding Analytical Methods Chapter in Part III of the HSM identified the relationship between vertical alignment and safety as reported in *Prediction of the Expected Safety Performance of Rural Two-Lane Highways*. Vertical curves are considered in the base model based on the crest vertical curve grade rate within the roadway segment with a level roadway section as the nominal condition. This is modified using a crash modification function. The crash risk increases as the grade of the roadway section increases, regardless of direction.

Relevant information on the effect of vertical alignment on safety developed during the research on rural multilane highways and suburban and urban arterials for the corresponding Analytical Methods Chapters in Part III of the HSM will be inserted in this location upon the completion of the research.

Special Features

Truck climbing lanes are short roadway segments that allow slow moving vehicles to "climb" grades while other vehicles pass. This subsection will include information on the safety effect of adding climbing lanes on roadway segments with steep upgrades. The relationship between crashes on roadway segments with climbing lanes will be compared to the crashes on similar roadway segments without climbing lanes.

Research on rural two-lane highways for Part III of the HSM addressed the relationship climbing lanes and safety together with passing lanes and short four-lane sections. In the rural two-lane segment base model, the nominal condition is without climbing lanes. The presence of climbing lanes is accounted for in a crash modification factor. They reduce the crash risk. Table A- 7 identifies some potential resources.

Table A- 7: Potential resources on the relationship between truck climbing lanes and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1991	St John and Harwood, "Safety Considerations for Truck Climbing Lanes on Rural Highways"	Combined truck speed profiles with crash rates based on speed variance to estimate the effect of climbing trucks on safety	Potential resource
1990	Khan and Holtz, "Cost Effectiveness of Climbing Lanes: Safety, Level of Service and Cost Factors"	Citation from the Ministry of Transportation of British Columbia library e-catalogue	Potential Resource; details unknown

3.2 SAFETY EFFECTS OF TRAFFIC CONTROL AND OTHER OPERATIONAL ELEMENTS

This section will contain information on the safety effects of traffic control devices and operational elements of roadway segments.

Signs, Delineation, and Pavement Markings

This section should provide a discussion on whatever is known on the safety effects of signs, pavement markings and markers, and roadside delineation. This would include all that is known on the effects on crashes and on safety measures. It is recommended that the author thoroughly review documentation prepared under NCHRP Project 5-17. This section will provide information on the safety effects of signs, delineation, and pavement markings. For information on delineation, the reader will be directed to the FHWA publication, "Roadway Delineation Practices Handbook". Table A- 8 identifies some potential references for this section.

Table A- 8: Potential resources on the relationship between pavement markings and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2000	Storm, "Pavement Markings and Incident Reduction"	Report includes a literature review on the effect of pavement markings; potentially identifies relevant sources	May identify sources
1994	Al-Masaeid and Sinha, "Analysis of Accident Reduction Potentials of Pavement Markings"	Evaluated the effect of safety of pavement markings used on undivided rural roads; 100 roads in Indiana	Potential resource, limited to IN
1992	Miller, "The Benefit-Cost Analysis of Lane Marking" [Reference in *Road Work Safety Report,* vol. 2, no. 6]	Evaluated the safety benefits of longitudinal pavement markings	Potential resource although scope unidentified
1986	Agent and Creasey, "Delineation of Horizontal Curves"	Investigate the effect of traffic control devices such as raised pavement markings and signs on driver behavior at horizontal curves; unclear if study was just limited to laboratory testing	Potential resource although scope unidentified
1985	Glennon, "Accident Effects of Centerline Markings on Low-Volume Rural Roads"	Compared the crash experience of various centerline treatments used on low-volume rural roads; used Pavement Marking Demonstration Program data	Potential resource

Shoulder, Transverse, and Centerline Rumble Strips

Rumble strips are used to provide a vibrotactile or audible warning to motorists. They are intended to reduce crashes caused by motorists leaving the roadway or entering into oncoming lanes. This section will provide information on the safety effects of using shoulder rumble strips or centerline rumble strips on roadway segments. This section will address the relationship between crashes on roadway segments with shoulder or centerline rumble strips to crashes on similar roadway segments without shoulder or centerline rumble strips. The effect of the rumble strips on the safety of bicyclists should also be addressed.

The reader will be directed to *NCHRP Synthesis of Highway Practice 191: Use of Rumble Strips to Enhance Safety* (TRB, 1993). The report discusses the safety effectiveness of rumble strips and presents information on their application.

No literature on the safety effect of centerline rumble strips or transverse rumble strips used on roadway segments was identified. Potential literature that provides information on the safety effect of shoulder rumble strips is summarized in Table A- 9.

Table A- 9: Potential resources on the safety effect of shoulder rumble strips.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	El-Gindy, "Development of Rumble Strip Configurations that are More Bicycle Friendly"	Conducted field evaluations of various rumble strip configurations, evaluated bicycle vertical acceleration and pitch angular acceleration	Potential resource although weak surrogate for bicycle safety
2000	Hanley et al., "Analysis of Accident-Reduction Factors on California State Highways"	Before and after study of crash data to evaluate the effect of rumble-strips as part of an update of ARFs. Employed Bayesian statistics and reported a statistically significant crash reduction potential.	Limited to California data.
1999	Griffith, "Safety Evaluation of Rolled-In Continuous Shoulder Rumble Strips Installed on Freeways"	Used HSIS data (CA and IL) to conduct a before and after evaluation of crashes on segments with rumble strips.	Potentially applicable although limited to CA and IL data
1998	Perrillo, "The Effectiveness and Use of Continuous Shoulder Rumble Strips"	Conducted a before and after evaluation on the effect on crashes of rumble strip installation in New York.	Limited to New York data.
1997	Hickey, "Shoulder Rumble Strip Effectiveness: Drift-Off-Road Accident Reductions on the Pennsylvania Turnpike"	Conducted a before and after evaluation of the effect on crash rates on roadway segments with Sonic Nap Alert Pattern (SNAP) rumble strip installation.	Limited to Pennsylvania data and specific rumble strip.
1985	Ligon, "Effects of Shoulder Textured Treatment on Safety"	Before and after study with control of twenty-four shoulder sites in 11 states; analyzed the effect of shoulder texture treatment on crash experience	Potential resource

Speed Zoning

This section will provide information on the safety effects of speed zoning. Speed zoning is the practice of applying a speed limit to a section of highway that is different than the applicable speed limit on adjoining roadway segments. The relationship between crashes on roadway segments with speed zones will be compared to those roadway segments without speed zones.

Potential resources for this section are listed in Table A- 10.

Table A- 10: Potential resources on the relationship between speed zoning and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1998	TRB Special Report 254, Managing Speed	Reviews studies that provide information o the effectiveness of speed zoning	Identifies potential resources
1998	Stuster et al., "Synthesis of Safety Research Related to Speed and Speed Management"	A synthesis of research findings on the safety effects of measures including speed limits used to manage speed	Identifies potential resources
1997	Agent et al., "Evaluation of Speed Limits in Kentucky"	Evaluated the effect on crash rates of 100 speed zones in KY by comparing the speed zones to adjacent sections where the speed limit was not lowered.	Limited to Kentucky data
1997	"Safety, Speed and Speed Management: A Canadian Review"	Citation from the Ministry of Transportation of British Columbia library e-catalogue	Potential resource; details unknown
1988	Taylor and Coleman, "Analysis of Speed Zoning Effectiveness: Final Report"	Conducted a before/after w/control study on the effect on crashes in twenty speed zones.	Limited to Michigan data
1984	Kadell, "The Traffic Safety Impact of Driver Improvement Countermeasures Targeting 55-MPH Speed Limit Compliance"	Citation from the Ministry of Transportation of British Columbia library e-catalogue	Type of countermeasures unclear

Passing on Two-Lane Roads

This section will provide information on the safety effect of the operational decision to permit passing on two-lane roads without providing a passing lane (i.e. a passing zone). This section will address the relationship between crashes in passing zones to no-passing zones.

Potential resources on the relationship between passing and safety are identified in Table A- 11.

Table A- 11: Potential resources on the relationship between passing zones and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1998	Hassan et al., "Design Considerations for Passing Sight Distance and Passing Zones"	Revises the model to determine PSD for passing zones; critically reviews relevant literature	Identifies potential literature
1977	Harwood and Glennon, "Framework for Design and Operation of Passing Zones on Two-Lane Highways"	Identified as Hassan as summarizing experimental findings	Potentially identifies literature
1970	Jones, "An Evaluation of the Safety and Utilization of Short Passing Sections"	Identified as Hassan as applicable study	Potential resource

On-Street Parking

This section will provide information on the safety effect of on-street parking on roadway segments. The effect on the safety of motorists, pedestrians, and bicyclists will be addressed. Crashes on roadway segments with on-street parking will be compared to crashes on similar roadway segments without on-street parking. On-street parking configuration and parking on one side versus both sides will also be addressed.

Potential resources on the relationship between on-street parking and safety are identified in Table A- 12.

Table A- 12: Potential resources on the relationship between on-street parking and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2002	Box, "Angle Parking Issues Revisited, 2001"	Summarizes data from published and unpublished data on the safety effect of parking; compares findings to 1978 FHWA findings; considers street classification	Highly relevant resource
1999	Hunter and Stewart, "An Evaluation Of Bike Lanes Adjacent To Motor Vehicle Parking"	Cross sectional study of two configurations of bicycle lanes in combination with on-street parking	Limited to just two cities, may not have evaluated safety
1991	McCoy et al., "Safety Evaluation Of Converting On-Street Parking From Parallel To Angle"	Before and after study evaluated the effects of converted on-street parallel parking to angle parking in Lincoln, Nebraska	Limited to Lincoln Nebraska
1978	Humphreys et al., "Safety Aspects Of Curb Parking"	FHWA report analyzed the relationship between on-street parking and crashes using data from 10 cities	Over 20 years old

Intelligent Transportation Systems and Traffic Management Systems

[Future HSM Edition]

This section will provide information on the safety effects of intelligent transportation systems and traffic management systems. This section will identify the relationship between traffic management and crashes on a roadway segment. It will contain information on the safety effect of progressed traffic signals as opposed to uncoordinated signal systems.

Editor's Note: In response to JSC reviewer's comments, this section was moved out of the chapter on Road Network Considerations to this chapter, Roadway Segments. However, some of the topics address network considerations that involve decisions operational decisions that affect intersections, for example, traffic signal progression. Potential references were identified although this section is recommended for future HSM editions due to the limited availability of adequate research.

Potential resources for this section are identified in Table A- 13.

Table A- 13: Potential resources on the relationship between intelligent transportation systems and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1998	Jernigan, "Expected Safety Benefits of Implementing Intelligent Transportation Systems in Virginia: A Synthesis of the Literature"	A comprehensive review of studies on the potential safety benefits of ITS; identifies many relevant studies; is not a critical review	Highly relevant literature review; identifies potential resources
1998	Sinha et al., "Evaluation of the Impacts of ITS Technologies on the Borman Expressway Network"	Study evaluated the impacts of a mini ATMS on the safety of the Borman expressway and vicinity; 3 mile section of freeway had ATMS system	Limited to one small system in IN
1998	Annino, "The Effects of ITS Technologies on Accident Rates"	Study evaluated the effect of ITS on crash frequency on diversionary roadways; I-95 corridor in southwestern Connecticut	Limited to one area in CT
1997	Zein, et al. [Title unknown]	Evaluated 22 the effect on crashes of adaptive control strategies system in North America and Europe	Potential resource although details of evaluation unknown
1997	Henk, "San Antonio's Transguide: Analysis of the Benefits"	Identified by Jernigan; series of before and after analyses; evaluated the effectiveness of San Antonio ATMS; estimated annual benefits	Limited to one system in TX
1996	Persaud et al., "Safety Evaluation of Freeway Traffic Management System in Toronto, Canada"	Before and after study that evaluated the effect of a freeway traffic management system on crashes	Limited to one facility in Canada
1989	Minnesota Department of Transportation, "Freeway Traffic Management Program: Status Report"	Identified by Jernigan; reported on reductions in crashes from freeway management system in Minneapolis/St. Paul area	Limited to Twin Cities

Traffic Calming

This section will provide information on the safety effect of traffic calming measures used on roadway segments. The measures and strategies are categorized as measures that are intended to prevent or restrict traffic movements, reduce speeds, or attract drivers' attention. This section should also include discussion of the effects of traffic calming on requirements of the Americans with Disability Act (ADA) and on emergency medical services. Potential items to be included in this section:

– *Chokers/Curb Bulbs*

– *Pavement Undulations*

– *Raised Crosswalks*

– *Speed Humps*

– *Rumble Strips*

The reader will be directed to the 1999 FHWA report, "Traffic Calming: State of the Practice".

Because of the diversity in traffic calming devices and their relatively new introduction in the U.S., not all devices have been evaluated. Some potential resources are listed in Table A- 14. Three of the resources listed present the findings of evaluations that were conducted outside of the U.S.

Table A- 14: Potential resources on the relationship between traffic calming and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	Ewing, "Impacts of Traffic Calming"	Summarizes the results of hundreds of before-and-after studies of traffic calming	Potential resource
2001	Cynecki and Huang, "The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior"	Evaluated numerous traffic calming measures using before and after studies in 3 cities, and cross-sectional studies in 5 cities; employed surrogates (e.g., speeds and compliance)	Potential resource
2000	Elvik, "Area-wide Urban Traffic Calming Schemes: A Meta-Analysis of Safety Effects"	A meta-analysis of 33 studies that evaluated the effect of traffic calming on safety	Potential resource
1998	Gardner et al., "Measuring the Safety Effect of Raised Bicycle Crossings Using a New Research Methodology"	Before and after study of raised urban bicycle crossings in Sweden	Potential resource although outside U.S.
1998	Mertner and Jorgense, "Effects of Traffic Calming Schemes in Denmark"	Before and after study of traffic calming in Denmark, evaluated safety	Potential resource although outside U.S.
1997	Zein, et al., "Safety Benefits of Traffic Calming"	Conducted a study of the safety benefits of traffic calming at four sites in Vancouver; also reviewed 85 case studies from Europe, Australia and North America	Case study limited to 4 sites in Canada; Identifies potential sources elsewhere

3.3 PEDESTRIAN AND BICYCLE SAFETY ON ROADWAY SEGMENTS

The following sections apply to pedestrian and bicycle considerations on roadway segments only. Bicycle and pedestrian safety at intersections is addressed in Chapter 4. This section will direct readers to the following publications: the FHWA publication, "Pedestrian Facilities Users Guide: Providing Safety and Mobility", the ITE publication, "Providing Safety and Mobility: Design and Safety of Pedestrian Facilities"; the ITE publication, "Design and Safety of Pedestrian Facilities"; the FHWA publication, "Safety Effectiveness of Highway Design Elements. Volume VI: Pedestrians and Bicyclists"; and the FHWA publication "Effects of Bicycle Accommodation on Bicycle/Motor Vehicle Safety and Traffic Operations". Depending on their applicability, it may also direct readers to international resources such as the AARB Transport Research and UNC publication, "Pedestrian Safety in Australia", the Lund University and Highway Safety Research Center publication, "Pedestrian Safety in Sweden", or "Research, Development and Implementation of Pedestrian Safety Facilities in the United Kingdom". This section should also include discussion of the Americans with Disabilities Act (ADA) within the context of pedestrian and bicycle safety on roadway segments.

> ***Editor's Note:*** *The author(s) of this section should familiarize themselves with the Pedestrian and Bicycling Information Center, available on the Internet at www.walkinginfo.org or www.bicyclinginfo.org. The websites provide numerous resources for this section.*

Bicycle Routes

This section will provide information on the safety effects of providing bicycle routes on roadways segments. Bicycle routes are provided on roadway segments in various forms including wide paved shoulders and bicycle lanes. The relationship between crashes on roadway segments with various treatments to accommodate bicycles will be compared with roadway segments that do not have accommodations for bicycles, but still have bicycle traffic.

Potential resources on the relationship between bicycle treatments and safety are identified in Table A- 15.

Table A- 15: Potential resources on the relationship between bicycle treatments and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1999	Hunter et al., "A Comparative Analysis of Bicycle Lanes versus Wide Curb Lanes: Final Report"	Comparative analysis of bicycle lanes versus wide curb lanes, sites in CA, FL, and TX, used conflicts as surrogate for safety	Potential resource
1997	Harkey and Stewart, "Evaluation of Shared-Use Facilities for Bicycles and Motor Vehicles"	Used observations of bicyclist and motor vehicle interactions in FL to evaluate the safety of shared-use facilities; wide curb lanes, bicycle lanes, and paved shoulders	Potential resource, limited to FL data

Sidewalks

This section will provide information on the safety effect of providing sidewalks for pedestrians parallel to roadway segments. The relationship between pedestrian and motor vehicle crashes, specifically 'run off road' or 'walking along roadway' crashes, on roadway segments with sidewalks will be compared to roadway segments without sidewalks.

Potential resources on the relationship between the provision of sidewalks and safety are identified in Table A- 16.

Table A- 16: Potential resources on the relationship between the provision of sidewalks and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1999	McMahon et al., “Analysis of Factors Contributing to ‘Walking Along Roadway’ Crashes”	Analyzed crash data at 47 crash sites and 94 comparison sites; identified the relationship between the provision of sidewalks and ‘walking along roadway’ crashes	Potential resource
1991*	Zegeer, “Synthesis of Safety Research: Pedestrians”	Synthesis of past research on pedestrians including the effect on pedestrian safety of sidewalks	Identifies potential sources
1987	Knoblauch et al., “Investigation of Exposure-Based Pedestrian Accident Areas: Crosswalks, Sidewalks, Local Streets, and Major Arterials”	Analyzed pedestrian collisions and exposure under various roadway situations, identified a relationship between pedestrian crashes and the provision of sidewalks by functional class	Potential resource

*An update of Zegeer’s 1991 synthesis was completed in 2001 and will soon be released as an FHWA report.

Mid-block Pedestrian Crossings

This section will provide information on the safety effect of providing unsignalized, non-intersection, or mid-block, pedestrian crossings across roadway segments. The relationship between motor vehicle and pedestrian crashes at uncontrolled, marked crosswalks versus uncontrolled, unmarked crosswalks will be identified. Additionally, the safety effect that refuges such as medians can provide to mid-block crossings should be identified.

Potential resources on the relationship between the mid-block pedestrian crossings and safety are identified in Table A- 17.

Editor's Note: Intersection crosswalks are addressed in Chapter 4.

Table A- 17: Potential resources on the relationship between the mid-block pedestrian crossings and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	Zeeger et al., "Safety Effects of Marked vs Unmarked Crosswalks at Uncontrolled Locations"	Matched comparison of 5 years of crash data at 1,000 marked crosswalks and 1,000 unmarked crosswalks	Potential resource
2001	Nitzburg and Knoblauch, "An Evaluation of High-Visibility Crosswalk Treatments—Clearwater Florida"	Before and after study with control on the effect of novel high visibility crosswalk, evaluated driver yielding, pedestrian behavior, and conflicts	Potential resource although novel system
1994	Bowman and Vecellio, "Effects of Urban and Suburban Median Types on Both Vehicular and Pedestrian Safety"	Evaluated the safety effect of various median types on both vehicular and pedestrian safety; analyzed over 30,000 crashes; 3 cities	Potential resource
1991*	Zegeer, "Synthesis of Safety Research: Pedestrians"	Synthesis of past research on pedestrians including the effect on pedestrian safety of crosswalks	Identifies potential sources

*An update of Zegeer's 1991 synthesis was completed in 2001 and will soon be released as an FHWA report.

3.4 SAFETY EFFECTS OF OTHER ELEMENTS

Highway Lighting and Illumination

This section will identify the safety effects of illumination on roadway segments. The section will address the relationship between crashes on roadway segments with no street lights versus crashes on roadway segments with street lights. This section should refer the user back to section 2.4, Human Factors in Road Safety, for a discussion on conspicuity and lighting.

Potential resources on the relationship between the highway light on roadway segments and safety are identified in Table A- 18.

Table A- 18: Potential resources on the relationship between the highway light on roadway segments and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1995	Elvik, "Meta-Analysis of Evaluations of Public Lighting as Accident Countermeasure"	Meta-analysis of 37 studies on the safety effect of illumination; illumination of various types of roadway segments included	Potential resource
1994	Griffith, "Comparison of the Safety of Lighting Options on Urban Freeways"	Used crash data to compare the safety of continuously lighted urban freeways and urban freeways with interchange lighting only	Limited to freeways in one metropolitan area
1989	Box, "Major Road Accident Reduction by Illumination"	Before and after study on the effect on crashes of illumination at one site, 2.8 km in length	Limited to one site

Weather Issues

Adverse Weather and Low Visibility Systems

Some transportation agencies employ advanced highway weather information systems that warn of the occurrence of adverse weather, including icy conditions, or low visibility. The safety effect that these systems have on roadway segments will be identified. The relationship between crashes on roadway segments with adverse weather systems or low visibility systems and crashes on roadway segments without these systems will be addressed.

The reader will be directed to *NCHRP Synthesis of Highway Practice 158: Wet-Pavement Safety Programs.* It provides information on reducing wet-pavement crashes.

Potential resources on the relationship between adverse weather systems and safety are identified in Table A- 19.

Snow and Ice control

This section will address the effect that adverse weather such as snow or ice has on the safety of roadways segments. This section will also identify the effect that snow and ice control such as anti-icing systems and snow removal have on the safety of roadway segments. The relationship between crashes on roadway segments with snow and anti-icing measures will be compared to crashes on roadway segments without snow and ice control measures. Potential resources on the relationship between snow and ice control and safety are identified in Table A- 20.

One-way Street Systems

(Future HSM Edition)

Table A- 19: Potential resources on the relationship between adverse weather systems and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	Carson and Mannering, "The Effect of Ice Warning Signs on Ice-Accident Frequencies and Severities"	Studied the effect of ice warning signs on crash frequency and severity in WA.	Potential resource, limited to WA
2000	Kyte et al., "Idaho Storm Warning System Operational Test"	Evaluated the effect of a Storm Warning System on safety; did not analyze crashes, used speed a surrogate for safety	Limited to one system, only analyzed speed
1997	Hogema and van der Horst, "Evaluation of A16 Motorway Fog-Signaling System with Respect to Driving Behavior"	Evaluated the effect of an automatic fog-signaling system on driver behavior in the Netherlands; used surrogate measures for safety	Limited to one 12 mile long system
1995	Kumala et al., "Safety Evaluation in Practice: Weather Warning Systems"	Studied the effect of a Road Weather Warning System in Finland on speed and headway	System scoped unknown, used surrogates
1993	FHWA, "Ice Detection and Highway Weather Information System—Summary Report"	Reports the results of evaluations conducted by 8 states of their ice detection and highway weather information systems; potential for crashes due to icy conditions was one of the aspects evaluated	Potential resource

Table A- 20: Potential resources on the relationship between snow and ice control and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	Khattak and Knapp, "Interstate Highway Crash Injuries During Winter Snow and Nonsnow Events"	Compare crashes and occupant injuries reported on Interstate highways in Iowa during winter snow event periods to winter nonsnow event periods; controlled for other factors	Potential resource, limited to IA
1999	Friar and Decker, "Evaluation of a Fixed Anti-Icing Spray System"	Before and after study of the effect of an anti-icing system on crashes; one location in Utah	Limited to one site
1997	Hanbali, "Criterion for Evaluating The Effectiveness Of Winter Road Maintenance On Traffic Safety"	Analyzes the effect of snow and icy conditions and their countermeasures on traffic safety	Potential resource
1994	Hanbali, "Economic Impacts of Winter Road Maintenance on Road Users"	Evaluated the effect on safety of winter road maintenance operations	Potential resource
1994	Savenhed, "Relationship Between Winter Road Maintenance and Road Safety"	Evaluated the crash risk of before and after winter road maintenance	Potential resource

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CHAPTER 4. INTERSECTIONS

This chapter will provide information on the safety effects of design, traffic control, and operational elements at intersections.

The reader will be directed to the FHWA publication, "Safety Effectiveness of Highway Design Elements. Volume V: Intersections".

4.1 SAFETY EFFECTS OF INTERSECTION DESIGN ELEMENTS

Information on the safety effects of intersection design elements will be developed as part of the research for Part III of the HSM and inserted in this location of the HSM. These chapters are expected to include rural two-lane highways, rural multilane highways, and urban and suburban arterials. The urban and suburban arterials chapter will call for research results that are currently being developed in NCHRP Project 17-26, Development of Models for Prediction of Expected Safety Performance for Urban and Suburban Arterials. If the research is completed in time, the knowledge will be used here.

Only those pieces of knowledge that were included in the analytical chapters should be included here, unless there are additional variables which could not be included in the models, about which some knowledge base can still be provided.

This section will direct readers to the FHWA publication, "Safety Effectiveness of Highway Design Features. Volume V: Intersections". Another potential resource is the FHWA publication, "Intersection Geometric Design and Operational Guidelines for Older Drivers and Pedestrians".

> *Editor's Note: The author of this section should familiarize themselves with NCHRP Synthesis of Highway Practice 299: Recent Geometric Design Research for Improved Safety and Operations.*

Intersection Geometry

Information to be provided by MRI as part of their work effort on the draft prototype chapter for 17-18(4) adequately addresses this section. Additionally, this section will also address unconventional intersection designs such as Michigan U-turn intersections and jughandles.

Potential resources on the relationship between intersection geometry and safety are identified in Table A- 21.

Table A- 21: Potential resources on the relationship between intersection geometry and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	Xu, "Right Turns Followed by U-Turns vs. Direct Left Turns: A Comparison of Safety Issues"	Reviewed crash experience of 250 sites in FL; included eight-lane, six-lane, and four-lane divided arterials	Limited to FL data
2000	Bauer and Harwood, Statistical Models of At-Grade Intersections—Addendum [to 1996 version]"	Used crash data to develop statistical models of the relationship between traffic crashes and highway geometric elements for at-grade intersections	Highly relevant resource

Roundabouts

This section will provide basic information on the safety effects of roundabouts. The crash experience of roundabout intersections will be compared with other intersection designs for similar highway conditions. It will direct readers to FHWA's roundabout guide for more detailed information.

Potential resource on the relationship between roundabouts and safety are identified in Table A- 22.

Table A- 22: Potential resource on the relationship between roundabouts and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	Persaud et al., “Safety Effect of Roundabout Conversions in the United States: Empirical Bayes Observational Before-After Study”	Before-after study of the effect on crashes at 23 intersections following change from stop and signal control to roundabout design; seven states, both urban, suburban, and rural	Highly relevant resource
2001	Flannery, “Geometric Design and Safety Aspects of Roundabouts”	Used crash data to identify geometric characteristics of roundabouts that affect safety; MD, FL, and NV	Potential resource if qualitative results are reported
2000	Persaud, et al., “Crash Reductions Following Installation of Roundabouts in the United States”	Before and after study of the effect on crashes resulting from the installation of roundabouts; 24 intersections in 8 states; used EB statistics; urban, rural, and suburban	Highly relevant resource
1999	Flannery and Elefteriadou, “A Review of Roundabout Safety Performance in the United States”	Before and after study of the effect on crashes of roundabouts, 3 intersections in FL and 5 in MD	Potential resource, limited to FL and MD
1997	Elvik et al, “Traffic Safety Handbook”	Identified by Garder et al. [above] as including a thorough review of literature on safety effects of roundabouts	Identified potential sources
1996	Brude, “Safety of Cyclists at Roundabouts: A Comparison between Swedish, Danish, and Dutch Results”	Citation from the Ministry of Transportation of British Columbia library e-catalogue	Potential international resource; details unknown
1995	Brown, *The Design of Roundabouts: State of the Art Review*	Review of studies on roundabouts	Identifies potential sources
1994	Schoon and van Minnen, “The Safety of Roundabouts in the Netherlands”	Before and after study of crashes at 181 intersections in the Netherlands converted to roundabouts	Potential international resource
--	Corben, “Crashes at Traffic Signals: Guidelines for a Traffic Engineering Safety Program of Replacing Selected Intersection Signals with Roundabouts”	Citation from the Ministry of Transportation of British Columbia library e-catalogue	Potential international resource; details unknown

Horizontal and Vertical Alignments of Intersection Approaches

[Future Edition]

This section will provide information on the safety effect of the horizontal and vertical alignment of an approach to an intersection. The effect that alignment has on sight distance and safety should be addressed. This section will compare crashes on intersection approaches that have horizontal or vertical curves to crashes on similar approaches that have flat, straight alignments. The safety effect of realigning intersections or flatting approaches will be identified.

The research on rural two-way highways for the corresponding Analytical Methods Chapter in Part III of the HSM, considered the horizontal and vertical approach alignment only as it related to sight distance (see below.)

Relevant information on the effect of the horizontal alignment and vertical alignment of intersection approaches on safety developed during the research on rural multilane highways and suburban and urban arterials for Part III of the HSM will be inserted in this location upon the completion of the research. An additional potential resource for this section is the 2001 Davis et al. publication, "Safety Benefits of Intersection Approach Realignment on Rural Two-Lane Highways."

There is little quantitative research available on the effect of sight distance and safety at intersections. The reader would be directed to *NCHRP Report 383: Intersection Sight Distance* for more information.

Left and Right Turn Lanes and Treatments

Information on the safety effects of conventional single turns for rural two-lane highways was developed as part of the research for the corresponding Analytical Methods Chapter in Part III of the HSM. The relationship between the presence of left and right-turn lanes at intersections and safety was identified as reported in *Prediction of the Expected Safety Performance of Rural Two-Lane Highways*. For the base models, the absence of right or left-turn lanes is the nominal condition. The presence of both right and left-turn lanes is included as crash modification factors. The presence of turn lanes decreases the crash risk at the intersection, the magnitude of which depends on the number of major-road approaches with turn lanes and the traffic control at the intersection.

Relevant information on the effect of the right and left-turn lanes on intersection safety developed during the research on rural multilane highways and suburban and urban arterials for the corresponding Analytical Methods Chapters in Part III of the HSM will be inserted in this location upon the completion of the research. It is anticipated that this research will also include information on the effect of dual left turn lanes.

The safety effect of other turn lanes elements to be addressed in the HSM include triple left turn lanes, dual right turn lanes, offset left turn lanes, and bypass lanes. This section should address the safety effect of the storage length of the turn lane.

Some potential resources for this section are identified in Table A- 23.

Table A- 23: Potential resources on the safety relationship of left and right turn lanes and treatments.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2002	Harwood et al., "Safety Effectiveness of Intersection Left- and Right-Turn Lanes"	Conducted a well designed before and after with control study of adding left turns lanes, adding right turn lanes, or extending the length of the lanes at intersections	Highly relevant resource
1999	Dixon et al., "Right-Turn Treatment for Signalized Intersections"	Study of right-turn strategies; comparative analysis of two-years of crash history at the intersections in Atlanta	Potential resource, limited to one metropolitan area
1999	Preston and Schoenecker, "Bypass Lane Safety, Operations, and Design Study"	Before and after analysis of bypass lanes affect on crashes in rural Minnesota	Potential resource, limited to MN
1998	Tarrall and Dixon, "Conflict Analysis for Double Left-Turn Lanes with Protected-Plus-Permitted Signal Phases"	Used traffic conflicts to assess the safety effect of three double-left turn lanes with protected-plus-permitted phasing, metro Atlanta	Limited to three intersections in Atlanta
1995	ITE, "Permissive Double Left Turns: Are They Safe?"	Comparison of crash rates at signals with single and double left turns operating with permissive and protect-only phasing in Denver and Colorado Springs metro areas	Potential resource, limited to CO
1989	McCoy and Malone, "Safety Effects of Left-Turn Lanes on Urban Four-Lane Roadways"	Used crash data at signalized and unsignalized intersections in NE to determine the effect of left turn lanes on safety	Potential resource, limited to NE

The reader would be directed to *NCHRP Report 279: Intersection Channelization Design Guide* (TRB, 1985) for additional information on factors to consider for constructing right-turn lanes or for design guidelines (e.g., taper length, storage lane length, and corner radius design guidelines) for right-turn lanes. The report also addresses multiple turn lanes. The reader will also be directed to *NCHRP Report 375: Median Intersection Design* (TRB, 1995) for information on the safety effects of median width at rural and suburban divided highway intersections.

Auxiliary Through Lanes

[Future Edition]

Auxiliary through lanes are used at intersection to increase the capacity of through traffic. This section will identify the effect of auxiliary through lanes on the safety of the intersection.

Sight Distance

This section will provide information on the effect of sight distance at intersections on safety.

Research on rural two-lane highways for the corresponding Analytical Methods Chapter in Part III of the HSM identified the relationship between intersection sight distance and safety as reported in *Prediction of the Expected Safety Performance of Rural Two-Lane Highways*. Sight distance due to roadway aliment or terrain was considered for the crash prediction algorithm. For the base models for intersections, adequate sight distance was the nominal condition. This is modified through a crash modification factor. The crash risk increases for each of the quadrants where the sight distance is less than the sight distance specified by AASHTO policy for a design speed of 20 km/h less than the major-road design speed.

Relevant information on the effect of the intersection sight distance on safety developed during the research on rural multilane highways and suburban and urban arterials for the corresponding Analytical Methods Chapters in Part III of the HSM will be inserted in this location upon the completion of the research.

Pedestrian and Bicyclists

Pedestrian Crossing Design

This section will provide information on the safety effect of design elements of pedestrian crossings at highway intersections. This section will direct readers to the following publications: the FHWA publication, “Pedestrian Facilities Users Guide: Providing Safety and Mobility”, the ITE publication, “Providing Safety and Mobility: Design and Safety of Pedestrian Facilities”; the ITE publication, “Design and Safety of Pedestrian Facilities”; and the FHWA publication, “Safety Effectiveness of Highway Design Elements. Volume VI: Pedestrians and Bicyclists”.

Editor's Note: *The author(s) of this section should familiarize themselves with the Pedestrian and Bicycling Information Center, available on the Internet at www.walkinginfo.org or www.bicyclinginfo.org. The websites provide numerous resources for this section.*

Crosswalk Markings

This subsection will evaluate the safety effect of marked crosswalks at unsignalized intersections.

Median Refuge Islands

Some pedestrian crossings at intersections are designed with a median refuge island for pedestrians. This subsection will compare safety at pedestrian crossings at intersections with median refuge islands to similar pedestrian crossings without median refuge islands.

Bicycle Considerations

This section will provide information on design measures to accommodate bicyclists at signalized intersections. The safety effect of bicycle lanes adjacent to turn lanes and advance bicycle merging treatments will be addressed.

This section will direct readers to the following FHWA publications: "Safety Effectiveness of Highway Design Elements. Volume VI: Pedestrians and Bicyclists" and "Effects of Bicycle Accommodation on Bicycle/Motor Vehicle Safety and Traffic Operations".

Potential references for crosswalk markings and median refuge islands are provided in Table A- 24. Potential references for bicycle considerations are provided in Table A- 25.

Table A- 24: Potential resources on the safety effect of marked crosswalks and median refuges at unsignalized intersections.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	Knoblauch et al., "Pedestrian Crosswalk Case Studies: Sacramento, California; Richmond, Virginia; Buffalo, New York; Stillwater, Minnesota"	Before and after study of crosswalk markings at 11 unsignalized intersections in 4 cities, evaluated indirect measures such as driver and pedestrian behavior	Potential resource
2001	ITE Pedestrian and Bicycle Task Force report, "Alternative Treatments for At-Grade Pedestrian Crossings"	Summarizes various studies on pedestrian crossing treatments at uncontrolled intersections, signalized intersections, and mid-block signals	Identifies and summarizes potential sources
1991*	Zegeer, "Synthesis of Safety Research: Pedestrians"	Synthesis of past research on pedestrians including the effect on pedestrian safety of median refuge islands and crosswalks	Identifies potential sources
1977	Lalani, "Road Safety at Pedestrian Refuges"	Before and after study of the effect of pedestrian refuges on crashes; sites in London	Limited to one international city

Table A- 25: Potential resources on the safety effect of bicycle design treatments.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2000	Jensen and Gade, "Cyclist Safety at Signalised Junctions"	Danish study that evaluated the safety effect of advance bicycle merging treatments at intersections	International study, details unknown
2000	Hunter, "Evaluation of a Combined Bicycle Lane/Right-Turn Lane in Eugene, Oregon"	Compared conflicts at an intersection with a combined bicycle lane/right-turn lane to a similar intersection with a standard right lane and bike lane to the left in Eugene, Oregon	Potential resource, limited to one city and one experimental site
1999	Hunter et al., "A Comparative Analysis of Bicycle Lanes versus Wide Curb Lanes: Final Report"	Comparative analysis of bicycle lanes versus wide curb lanes, sites in CA, FL, and TX, used conflicts as surrogate for safety	Potential resource

Other Access Points in Close Proximity

This section will provide information on the safety effect of access points in close proximity to an intersection such as other intersections, driveways, and alleys.

Urban and Suburban

A potential reference for this section is the 1976 McGuirk and Satterly publication, "Evaluation of Factors Influencing Driveway Accidents."

> ***Editor's Note**: The author should also include a cross-reference in this section to Section 7.1, Access Management.*

Roadside Design

This section will provide information on the safety effect of the roadside design (e.g. clear zone, slope, etc.) on the approach to an intersection. The effect of roadside design on safety should be discussed in the context of both rural and urban environments.

The user should be referred back to section 2.4, Human Factors in Road Safety, for a discussion of some of the human factors issues of a roadside affect safety.

Relevant information on the effect on safety of the roadside design on the approach to an intersection developed during the research on rural multilane highways and suburban and urban arterials for the corresponding Analytical Methods Chapters in Part III of the HSM will be inserted in this location upon the completion of the research.

4.2 SAFETY EFFECTS OF INTERSECTION TRAFFIC CONTROL AND OPERATION ELEMENTS

Information on the safety effects of intersection traffic control and operational elements will be developed as part of the research for Part III of the HSM and inserted in this location of the HSM. These chapters are expected to include rural two-lane highways, rural multilane highways, and urban and suburban arterials. The urban and suburban arterials chapter will call for research results that are currently being developed in NCHRP Project 17-26, Development of Models for Prediction of Expected Safety Performance for Urban and Suburban Arterials. If the research is completed in time, the knowledge will be used here.

Only those pieces of knowledge that were included in the analytical chapters should be included here, unless there are additional variables which could not be included in the models, about which some knowledge base can still be provided.

This section will direct readers to the FHWA publications, *Safety Effectiveness of Highway Design Features. Volume V: Intersections*, the *Manual on Uniform Traffic Control Devices*, and the *Traffic Control Devices Handbook*. Another potential resource is the FHWA publication, *Intersection Geometric Design and Operational Guidelines for Older Drivers and Pedestrians*.

Channelization

This section will identify the safety effects of using traffic control devices (e.g. bollards or pavement markings) to channelize turns at intersections. The relationship between intersection crashes without channelization will be compared to crashes at similar intersections with channelization. Potential resources for this section are identified in Table A- 26.

Table A- 26: Potential resources on the relationship between channelization and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1999	Vogt, "Crash Models for Rural Intersections: Four-Lane by Two-Lane Stop-Controlled and Two-Lane By Two-Lane Signalized"	Analyzed the relationship between crashes and intersection elements (including channelization) at 3 types of rural intersections in CA and MI	Type of channelization unknown
1992	Gibby et al., "Evaluation of High-Speed Isolated Signalized Intersections in California (With Discussion and Closure)"	Analyzed the relationship between crashes and intersection elements (including channelization) at high-speed intersections in CA	Type of channelization unknown, limited scope in CA

Type of Traffic Control

Information on the safety effects of different types of traffic control for rural two-lane and multi-lane highways will be developed as part of the research for Part III of the HSM and inserted in this location of the HSM. If the information is unique, this section will contain information on the safety effect of traffic control at urban intersections. Potential resources for this section are provided in Table A- 27.

Table A- 27: Potential resources on the safety effect of intersection control at urban intersections.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2000	Bauer and Harwood, "Statistical Models of At-Grade Intersections—Addendum [to 1996 version]"	Used crash data to develop statistical models of the relationship between traffic crashes and highway geometric elements for at-grade intersections	Highly relevant resource
1987	Radwan, "Safety Effects of Traffic Signal Installations: State of the Art"	Comprehensive review of signal installation and their impact on crashes	Potential resource

Traffic Signal Operations

This section will identify the safety effect of elements of traffic signal operations at intersections including the left turn treatment, prohibition of right turns on red, actuated signal detector placement on the approach, and signal timing parameters. In addition to the publications mentioned at the beginning of this section, 'Safety Effects of Intersection Traffic Control and Operation Elements', the reader will be directed to the ITE publication, *Manual of Traffic Signal Design.*

Left Turn Operation

This subsection will identify the safety effect of various left turn operations at signalized intersections including protected, permitted, and protect/permitted left turn phasing. Information on the safety effect of protected left-turn signal phasing for rural two-lane and multi-lane highway intersections will be developed as part of the research for Part III of the HSM and inserted in this location of the HSM. This subsection will include information on the safety effects of left turn operation that are either not covered in Part III or are unique to urban and suburban arterials.

This subsection should also include information on the safety effects of leading versus lagging protected left turns. Crashes at intersections with leading protected left turn phasing will be compared to crashes at similar intersections with lagging protected left turn phasing.

Right Turn Operation

This subsection will provide information on the safety effect of right turn operations at signalized intersection. Crashes, especially pedestrian crashes, at signalized intersections where right turns are prohibited during the red signal indication will be compared to crashes at similar intersections where right turns are permitted during the red signal indication.

If the right turns during the red signal indication are prohibited, there are various methods used to prohibit them. This subsection will also identify the safety effectiveness of conditional prohibition (e.g. "No turn on red when pedestrians are present") versus constant prohibition.

> *Editor's Note: The author of this section should familiarize themselves with the 1994 NHTSA report to Congress, "Safety Impact of Permitting Right-Turn-On-Red."*

Detector Placement and Signal Control on High Speed Approaches

> *[Future Edition]*

The onset of the change interval at a signalized intersection can be timed so as to minimize the likelihood that a motorist will be a distance from the intersection where they may be indecisive about whether to stop or proceed through the intersection. Traffic detectors can be placed strategically to determine the optimum onset of the change interval. This subsection will identify the safety effect of detector placement on high-speed approaches to signalized intersections.

> *Editor's Note: Bonneson and McCoy (1996) developed recommended placement of detectors, but did not conduct an evaluation of the effect on safety.*

Phase and Cycle Duration

This subsection will contain information on the safety effects of timing parameters of a signalized intersection including the length of the yellow interval, the length and use of an all-red interval, and the cycle length. The relationship between the yellow interval length and crashes and the cycle length and crashes at intersections will be identified. The relationship between crashes at intersections that employ an all-red interval versus intersections that do not use an all-red interval will be identified.

Actuated Control

This section will also contain information on the safety effect of various types of traffic controls (i.e., fully actuated, semi-actuated, and pre-timed). A potential resource for this section is the 2000 Mohamedshah et al. publication, "Association of Selected Intersection Factors with Red-Light-Running Crashes."

Other Operational Considerations

This subsection will contain information on the safety effect of other traffic signal operational considerations such as the use of flashing signal operation. Flashing traffic signal operation can be used during low volume conditions to minimize delay at a signalized intersection. The subsection will identify the relationship between crashes at intersections during flashing operation to crashes at similar intersection operating in full signal operation.

Potential resources on the relationship between left turn operation and safety are provided in Table A- 28. Potential resources on the relationship between right turn operation and safety are provided in Table A- 29. Potential resources on the relationship between signal phases and safety are provided in Table A- 30. Potential resources on the relationship between various signal operational considerations and safety are provided in Table A- 31

Table A- 28: Potential resources on the relationship between left turn operation and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	Thomas and Smith, "Effectiveness of Roadway Safety Improvements"	Before and after study of the effect on crashes of safety projects in IA; includes projects that added left-turn phasing	Potential resource, limited to IA
1999	Sheffer and Janson, "Accident and Capacity Comparisons of Leading and Lagging Left-Turn Signal Phasings"	Compared crash rates between protected-only leading and lagging left-turn phases	Potential resource
1998	Tarrall and Dixon, "Conflict Analysis for Double Left-Turn Lanes with Protected-Plus-Permitted Signal Phases"	Before and after study evaluated the effect of converting a double left-turn lane from protected-plus-permitted to protected only phasing on conflicts, limited to one intersection in metro Atlanta	Limited to one intersection in Atlanta
1995	ITE, "Permissive Double Left Turns: Are They Safe?"	Comparison of crash rates at signals with single and double left turns operating with permissive and protect-only phasing in Denver and Colorado Springs metro areas	Potential resource, limited to CO
1995	Shebeeb, "Safety and Efficiency for Exclusive Left-Turn Lanes at Signalized Intersections"	Study evaluated the safety of various left turn movement phasings at signalized intersections; used crash data	Potential resource
1991	Lee et al., "Comparative Analysis of Leading and Lagging Left Turns"	Before and after study on the safety effects of conversion from leading to lagging protected left turn operation; intersections in 3 areas in AZ	Potential resource, limited to AZ

Table A- 29: Potential resources on the relationship between right turn operation and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2002	Lord, "Synthesis of the Safety of Right Turn on Red in the United States and Canada"	Reviews various studies	Identifies potential sources
2001	Retting et al., "Field Evaluations of Two Methods for Restricting Right Turn on Red to Promote Pedestrian Safety"	Evaluated the safety effect on pedestrians of RTOR restrictions at 15 intersections in Arlington, VA; used field observations of pedestrian and driver behavior; two experimental groups and one control group	Limited to one city
1994	Compton and Milton [Title unknown]	Evaluated the safety impact of permitting right-turn-on-red movements, used total crashes and fatal crashes, crashes with other motor vehicle and pedestrian crashes	Potential resource
1991*	Zegeer, "Synthesis of Safety Research: Pedestrians"	Synthesis of past research on pedestrians including the effect on pedestrian safety of right-turn-on-red operation	Identifies potential sources
1986	Zegeer and Cynecki, "Evaluation of Countermeasures Related to RTOR Accidents that involve Pedestrians"	Field evaluation of the effect of seven RTOR countermeasures on pedestrian safety; used conflicts and violations as surrogates; 34 intersections in 6 U.S. cities	Potential resource
1983	Clark et al., "Public Good Relative to Right-Turn-on-Red in South Carolina and Alabama"	Before and after study of the effect of RTOR laws on crashes at intersections in SC and AL	Potential resource, slightly outdated
1982	Preusser et al., "The Effect of Right-Turn-on-Red on Pedestrian and Bicyclist Accidents"	Evaluated the effect of a "Western" version of RTOR on pedestrian and bicycle crashes with motor vehicles; sites in NY, WI, OH, and LA	Potential resource, slightly outdated

*An update of Zegeer's 1991 synthesis was completed in 2001 and will soon be released as an FHWA report.

Table A- 30: Potential resources on the relationship between signal phases and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2002	Retting et al. [Title unknown]	Evaluated the crash effects of modifying the change interval; 122 intersection with a random before and after with control; examined crashes	Highly relevant resource
2000	Datta et al., "Red Light Violations and Crashes at Urban Intersections"	Before and after analysis to evaluate the effect of an all-red-interval on crashes; conducted in Detroit, MI	Limited to one city
1997	Retting and Greene, "Influence of Traffic Signal Timing on Red-Light Running and Potential Vehicle Conflicts at Urban Intersections"	Before and after study on the effect on safety of increased change intervals; used potential conflicts as surrogates; 10 urban intersections	Used potential conflicts, not conflicts or crashes
1992	Roper et al., "The Effects of the All-Red Clearance Interval on Intersection Accident Rates in Indiana"	Evaluated the short and long term effect of all-red intervals on crash rates at intersections in IN; used 7 years of crash data	Potential resource, limited to IN
1991	Bhesania, "Impact of Mast-Mounted Signal Heads on Accident Reduction"	Before and after study of the effect on crashes of installation of all-red interval at six intersections; signals were also converted to mast-mounted	Phase change combined with other treatment
1985	Zador et al., "Effect of Signal Timing on Traffic Flow and Crashes at Signalized Intersections"	Comparative analysis of traffic signal change interval timing and crashes at 91 intersections throughout the US	Potential resource

Table A- 31: Potential resources on the relationship between various signal operational considerations and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1998	Polanis, "Do 12 Inch Signal Lenses Reduce Angle Crashes?"	Describes the results of 38 before and after studies on the effect of 12 inch signal lenses on crashes in Winston-Salem, NC	Potential resource, limited to one city
1998	Sayed et al., "Safety Evaluation of Alternative Signal Head Design"	Empircal Bayes before and after crash analysis of the effect of increased signal head size at 10 urban intersections in British Columbia	Potential resource, limited to ten intersections in Canada
1987	Barbaresso, "Relative Accident Impacts of Traffic Control Strategies During Low-Volume Nighttime Periods"	Before and after study evaluated the effect on crashes of flashing operation at six 4-legged intersections; also conducted comparative analysis of crashes at intersections by signal operation	Before and after limited to six intersections

Advance Warning Flashers

An advance warning flasher (AWF) is a traffic control device that provides drivers with advance information on the status of a downstream traffic signal. This section will identify the effect of advance warning flashers on the safety of the intersection. Potential references for this section are identified in Table A- 32.

Table A- 32: Potential resources on the relationship between advanced warning flashers and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1999	Sayed et al., “Advance Warning Flashers: Do They Improve Safety”	Evaluated the effect of AWFs at signalized intersections in British Columbia on crash frequency; used 106 intersections	Potential international resource
1999	Farraher et al., “The Effect of Advanced Warning Flashers on Red Light Running—A Study Using Motion Imaging Recording System Technology at Trunk Highway 169 and Pioneer Trail in Bloomington, Minnesota”	Studied the effect of AWF in reducing red signal violations at an intersection in Bloomington, Minnesota	Limited to one intersection in MN; evaluated violations, not crashes

Pedestrian Traffic Control

This section will provide information on traffic control devices for pedestrians at intersections. These include illuminated push buttons, pedestrian detectors, countdown signals, signage, pedestrian channelization devices, and pedestrian intervals. Potential resources for this section are identified in Table A- 33.

> **Editor's Note:** The author(s) of this section should be familiar with the Pedestrian and Bicycling Information Center, available on the Internet at *www.walkinginfo.org* or *www.bicyclinginfo.org*. The websites provide numerous resources for this section. In addition to those references listed in the following table, the authors should also familiarize themselves with the FHWA publication, "Pedestrian Facilities Users Guide: Providing Safety and Mobility".

Table A- 33: Potential resources on the relationship between pedestrian traffic control devices and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	ITE Pedestrian and Bicycle Task Force report, "Alternative Treatments for At-Grade Pedestrian Crossings"	Summarizes various studies on pedestrian crossing treatments at uncontrolled intersections, signalized intersections, and mid-block signals	Identifies and summarizes potential sources
2001	Huang and Zegeer, "An Evaluation of Illuminated Pedestrian Push Buttons in Windsor, Ontario"	Evaluates illuminated push buttons at four intersections in Windsor, Ontario.	Potential resource, limited to one site
2001	Hughes et al., "Evaluation of Automated Pedestrian Detection at Signalized Intersections"	Before and after study, evaluated the effect of automated pedestrian detectors used in conjunction with push buttons on conflicts and inappropriate crossings in Los Angeles, CA, Phoenix, AZ, and Rochester, NY	Potential resource
2000	Leonard, "Behavioral Evaluation of Pedestrians and Motorists Towards Pedestrian Countdown Signals"	Evaluated the effect on pedestrian safety of pedestrian countdown signals at intersection using pedestrian and motorist behavior as a surrogate	Potential resource
1999	King, "Calming New York City Intersections"	Evaluated the effect of leading pedestrian intervals on crashes at 26 intersections in New York City; used a before and after study	Limited to NYC
1997	Van Houten et al., "Field Evaluation of a Leading Pedestrian Interval Signal Phase at Three Urban Intersections"	Evaluated the effect on safety of using a three-second leading pedestrian interval at three urban intersections; used pedestrian behavior and conflicts as surrogate	Limited to three intersections
1991*	Zegeer, "Synthesis of Safety Research: Pedestrians"	Synthesis of past research on pedestrians including the effect on pedestrian safety of traffic control	Identifies potential sources

*An update of Zegeer's 1991 synthesis was completed in 2001 and will soon be released as an FHWA report.

Signing, Marking and Delineation

This section will provide information on the safety effects of signs, pavement markings and delineation at signalized and unsignalized intersections. Potential resources for this section are identified in Table A- 34.

Table A- 34: Potential resources on the relationship between signs, marking, and delineation and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	ITE Pedestrian and Bicycle Task Force report, "Alternative Treatments for At-Grade Pedestrian Crossings"	Summarizes various studies on pedestrian crossing treatments at uncontrolled intersections, signalized intersections, and mid-block signals	Identifies and summarizes potential sources
2001	Malenfant et al., "Advance Yield Markings: Reducing Motor Vehicle-Pedestrian Conflicts at Multilane Crosswalks with Uncontrolled Approach"	Evaluated the effect of advance yield markings and a symbol sign on pedestrian safety at intersections; used pedestrian and motorist behavior as surrogate	Potential resource
2000	Storm, "Pavement Markings and Incident Reduction"	Includes literature review on the safety effectiveness of pavement markings	Identified potential sources
1994	Brich and Cottrell, "Guidelines for the Use of No U-Turn and No-Left Turn Signs"	Before and after study evaluated the effect of No U-Turn and No Left-Turn signs on crash rates at 8 signalized intersections	Limited to 8 intersections in VA
1986	Zegeer and Cynecki, "Evaluation of Countermeasures Related to RTOR Accidents that involve Pedestrians"	Field evaluation of the effect of advanced stop lines (pavement marking) on pedestrian safety; used conflicts and violations as surrogates; 34 intersections in 6 U.S. cities	Potential resource

Traffic Calming

This section will provide information on the safety effect of traffic calming measures used as intersections or on intersection approaches. The measures and strategies are categorized as measures that are intended to prevent or restrict traffic movements, reduce speeds, or attract drivers' attention. Potential items to be included in this section:

– *Chokers/Curb Bulbs*

– *Traffic Circles and Semidiverts*

– *Pavement Undulations*

– *Raised Intersections and Crosswalks*

– *Speed Humps*

– *Rumble Strips*

The reader will be directed to the 1999 FHWA report, "Traffic Calming: State of the Practice" and with the NHTSA report, "Literature Review on Vehicle Travel Speeds and Pedestrian Injuries".

Because of the diversity in traffic calming devices and their relatively new introduction in the U.S., not all devices have been evaluated. Some potential resources are listed in Table A- 35. Many of the resources listed present the findings of evaluations that were conducted outside of the U.S.

Table A- 35: Potential resources on the relationship betwen traffic calming at intersections and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	Ewing, "Impacts of Traffic Calming"	Summarizes the results of hundreds of before-and-after studies of traffic calming	Potential resource
2001	Cynecki and Huang, "The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior"	Evaluated numerous traffic calming measures using before and after studies in 3 cities, and cross-sectional studies in 5 cities; employed surrogates (e.g., speeds and compliance)	Potential resource
2001	ITE Pedestrian and Bicycle Task Force report, "Alternative Treatments for At-Grade Pedestrian Crossings"	Summarizes various studies on pedestrian crossing treatments at uncontrolled intersections, signalized intersections, and mid-block signals	Identifies and summarizes potential sources
2000	Elvik, "Area-wide Urban Traffic Calming Schemes: A Meta-Analysis of Safety Effects"	A meta-analysis of 33 studies that evaluated the effect of traffic calming on safety	Potential resource
1999	King, "Calming New York City Intersections"	Evaluated the effect of neckdowns on crashes at six locations in New York City; focused on pedestrian crashes	Limited to six intersections in one city
1998	Gardner et al., "Measuring the Safety Effect of Raised Bicycle Crossings Using a New Research Methodology"	Before and after study of raised urban bicycle crossings in Sweden	Potential resource although outside U.S.
1998	Mertner and Jorgense, "Effects of Traffic Calming Schemes in Denmark"	Before and after study of traffic calming in Denmark, evaluated safety	Potential resource although outside U.S.

4.3 SAFETY EFFECTS OF OTHER INTERSECTION-RELATED FEATURES

Transit Stop Placement

[Future Edition]

Illumination

The section will address the relationship between crashes at intersections with no street lights versus crashes at intersections with street lights. It will identify the effect of illumination on the crash risk of the intersection. Potential resources for this section are identified in Table A- 36.

Table A- 36: Potential resources on the relationship between illumination at intersections and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1999	Preston and Schoenecker, "Safety Impacts of Street Lighting at Rural Intersections"	Conducted both a cross-sectional study (3,400 intersections) and a before-and-after analysis (12 intersections) of the effect of street lighting on rural intersection safety	Potential resource, limited to MN
1995	Elvik, "Meta-Analysis of Evaluations of Public Lighting as Accident Countermeasure"	Meta-analysis of 37 studies on the safety effect of illumination; illumination of various types of roadway segments included	Potential resource
1991	Keck, "The Relationship of Fixed and Vehicular Lighting to Accidents"	Synthesis of lighting research from 1979 to 1988	May identify potential resources
1984	Anderson et al., "Cost-Effectiveness Evaluation of Rural Intersections Levels of Illumination"	Analyzed the effect on conflicts of various levels of illumination at one rural intersection	Limited to one intersection
1976	Lipinski and Wortman, "Effect of Illumination on Rural At-Grade Intersection Accidents"	Cross-sectional study, 445 rural intersections in IL	Old study, limited to IL

Automated Intersection Enforcement

> *NOTE TO JSC: There were conflicting thoughts on whether to include this section in the HSM. One reviewer noted that this was the only place that any type of "enforcement" was covered in the HSM, and that it should be omitted for consistency. The other side of this issue is that (1) there is continuing and increasing interest in the use of red-light-camera systems by local communities and state DOT's; (2) this is a unique type of enforcement in that decisions to use RLC systems and the implementation and maintenance of the systems involve traffic engineers and safety engineers (in addition to police enforcement agencies; and (3) FHWA is planning a major national evaluation of the crash related effects of RLC systems that will be completed by the end of 2004. Thus, crash-based guidance and safety information will exist for use in the first edition of the HSM.* ***The JSC will have to decide whether this section should be included***.

To the extent that it is possible, this section should also identify and describe safety effects related to automated Railroad-Highway Grade crossings and automated speed radar enforcement programs and systems. The author is urged to be clear on safety issue and be concerned particularly with the documented effects on safety. The author should be very careful in the selection of material for this section and in the specific language he/she uses because there are judicial issues to consider. The author should investigate more fully the latest findings from San Bernardino. If present, this section will contain information on the safety effect of red-light-camera systems at signalized intersections. FHWA's evaluation of the crash-related effects of RLC systems, including "spillover" effects to nearby untreated intersections, the effect of changes to yellow-interval or the use of all-red intervals on the RLC effectiveness, and other factors will be addressed. A critical review of past studies of RLC effectiveness and the proposed national evaluation design can be found in the 2002 unpublished reference in Table A- 37. The table also contains two other potential resources.

Table A- 37: Potential resources on the relationship between automated enforcement and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2002 (unpublished)	Council and Persaud, "Red Light Camera Safety Evaluation -- Experimental Design: Final Report," Prepared for FHWA's ITS Joint Programs Office	Proposed evaluation design for national study of crash effects of RLC systems. Includes critical reviews of past RLC studies	Potential resource
2000	Smith et al., "Automated Enforcement of Red Light Running Technology and Programs: A Review"	Evaluated the effect of automated enforcement systems on crashes and violations at intersections in three cities in the U.S., conducted in NY, FL, and MD	Potential resource
1999	McFadden and McGee, "Synthesis and Evaluation of Red Light Running Automated Enforcement Programs in the United States"	Evaluated the effect of automated enforcement systems on crashes and violations at intersections in five cities in the U.S.	Potential resource

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CHAPTER 5: INTERCHANGES

5.1 SAFETY EFFECTS OF INTERCHANGE DESIGN ELEMENTS

The reader will be directed to the 1992 FHWA publication, "Safety Effectiveness of Highway Design Features. Volume IV: Interchanges".

Interchange Type/Configuration

This section will contain information on the safety of various interchange types such as diamond, cloverleaf, single point, partial cloverleaf, and trumpet interchanges. As some interchange types are better suited for different applications (e.g. rural versus urban), the crash risk for interchange types in various applications will be addressed. The crash risk of freeway-to-freeway interchanges will also be discussed. Potential resources for this section are provided in Table A- 38.

Table A- 38: Potential resources on the relationship of interchange type and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1999	Garber and Fontaine, "Guidelines for Preliminary Selection of the Optimum Interchange Type for a Specific Location"	As part of a study to develop guidelines for selecting the interchange type, the safety characteristics of 10 interchanges in Virginia were studied.	Limited to 10 interchanges in VA
1996	Garber and Smith, "Comparison of the Operational and Safety Characteristics of the Single Point Urban and Diamond Interchanges"	Compared the accident experience of nine single point urban interchanges and eight diamond interchanges	Potential resource
1993	Twomey et al., "Accidents and Safety Associated with Interchanges"	Reviewed past research that studied the effect of interchange spacing on accidents	Identifies potential sources
1992	Twomey et al., "Safety Effectiveness of Highway Design Features. Volume IV: Interchanges"	Reviewed past research that studied the effect of interchange spacing on accidents	Identifies potential sources

Merge/Diverge Areas

This section will contain information on the safety effect of design elements of merge and diverge areas. The relative crash risk of various types of merge and diverge areas will be addressed, including two-lane merges and diverges, parallel versus taper merges, and left hand versus right hand merges and diverges. The effect on safety of the presence and length of deceleration and acceleration lanes will be provided. Potential resources for this section are provided in Table A- 39.

Table A- 39: Potential resources on the relationship between the design of merge and diverge areas and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1999	Janson et al., Effects Of Geometric Characteristics Of Interchanges On Truck Safety	Used crash data from WA, CO, and CA to identify relationships between truck accidents and geometric characteristics of interchanges including merge/diverge areas	Potential resource, limited to truck safety
1999	Bared et al., Safety Evaluation Of Acceleration And Deceleration Lane Lengths	Provides a method to estimate accident frequencies for ramps, as a function of speed-change lane length, among other variables	Potential resource
1998	Bauer and Harwood, Statistical Models Of Accidents On Interchange Ramps And Speed-Change Lanes	Used HSIS data from WA to explore the relationship between speed-change lanes and volumes and crashes	Potential resource
1993	Twomey et al., Accidents And Safety Associated With Interchanges	Reviewed past research that studied the effect of interchange design and accidents including acceleration and deceleration lanes	Identifies potential sources
1982	Synthesis of Safety Research Related to Traffic Control and Roadway Elements—Vol. 1.	Investigated the relationship between safety and interchange design features	20 years old

Ramps

This section will contain information on the safety effect of design elements of interchange ramps. The relative crash risk of various horizontal and vertical alignments will be presented. Potential resources for this section are provided in Table A- 40.

Table A- 40: Potential resources on the relationship between the design of interchange ramps and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1998	Khorashadi, "Effect of Ramp Type and Geometry on Accidents"	Accident rates were analyzed to assess the differences between ramp designs	Potential resource
1998	Bauer and Harwood, "Statistical Models of Accidents on Interchange Ramps and Speed-Change Lanes"	Used HSIS to explore the relationship between interchange ramp design and volumes and crashes	Potential resource
1993	Twomey et al., "Accidents and Safety Associated with Interchanges"	Reviewed past research that studied the effect of interchange design and accidents including acceleration and deceleration lanes	Identifies potential sources
1992	Twomey et al., "Safety Effectiveness of Highway Design Features. Volume IV: Interchanges"	Reviewed past research that studied the effect of ramp design on safety	Identifies potential sources

Ramp Terminals

This section will contain information on the safety effect of ramp terminal design elements such as sight distance, angle of merge, parallel versus taper design, left versus right-hand ramps, etc. This section will only address aspects of intersection safety that are unique to ramp terminals. A potential resource for this section is the 1970 Oppenlander and Dawson report, "Traffic Control & Roadway Elements – Their Relationship to Highway Safety, Revised."

> ***Editor's Note:*** *Cross streets will be treated as Intersections and as such, addressed in Chapter 4, Intersections, based on HCM terminology, not AASHTO terminology. The author of this chapter should provide a cross-reference to Chapter 4.*

Acceleration and Deceleration at Ramp Terminals

This section will provide information on safety effects of acceleration and deceleration lanes at the ramp terminal.

> *[Future Edition]*

Pedestrian Considerations

This section will contain information on the effect of interchange design elements on the safety of pedestrians at ramp terminals. This section will only address aspects of pedestrian safety at intersections that are unique to ramp terminals. Potential resources for this section are provided in Table A- 41.

Table A- 41: Potential resources on pedestrian safety at ramp terminals.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	Ferrara, "Statewide Safety Study of Bicycles and Pedestrians on Freeways Expressways, Toll Bridges, and Tunnels"	Conducted an analysis of bicycle and pedestrian collision data, in part to develop procedures for allowing bicyclists to cross ramps.	Potentially useful although limited to CA and in subject
1976	"NCHRP Synthesis of Highway Practice, Design and Control of Freeway Off-Ramp Terminals"	Comprehensive review includes information on accommodation of pedestrians and bicycles at interchanges	Potentially useful if quantitative research results are provided

Other Design Elements

Closely Spaced Intersections

[Future Edition]

This section will provide information on the effect of intersections closely spaced to interchanges on safety. A potential resource for this section is the 1983 Nordstrom and Stockton report, "Evaluation of Minor Freeway Modifications."

5.2 SAFETY EFFECTS OF TRAFFIC CONTROL AND OPERATIONS ELEMENTS

Traffic Control at Ramp Terminals

This section will provide information on the safety effect of the choice of traffic control at ramp terminals. Ramp terminals can be signalized, stop-controlled, free-flowing, or yield controlled. The relationship between the type of traffic control and crashes at ramp terminals will be identified. This section will only address aspects of intersection traffic control that are unique to ramp terminals. Potential resources for this section are provided in Table A- 42.

Table A- 42: Potential resources on the relationship between intersection traffic control and safety at ramp terminals.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1982	"Synthesis of Safety Research Related to Traffic Control and Roadway Elements—Volume 1"	Synthesis of safety research including traffic control at interchanges	May help identify other sources, 20 years old
1976	"NCHRP Synthesis of Highway Practice, Design and Control of Freeway Off-Ramp Terminals"	Comprehensive review includes information on traffic control device applications	More than 25 years old, potentially useful if quantitative research results are provided

Ramp Metering

[Future Edition]

This section will provide information on the safety effect of using ramp metering at ramp terminals. Ramp metering primarily used for congestion management, can also reduce motor vehicle crashes by reducing sideswipes in merge areas and reducing rear end crashes caused by vehicles merging during congestion. However, if not properly designed and operated, ramp meters could increase the crash risk on the surface streets. This subsection should address the effect of ramp metering on crash risk at an interchange, including the mainline crash risk, ramp crash risk, and the minor road crash risk. Potential resources for this section are provided in Table A- 43.

Table A- 43: Potential resources on the relationship to ramp metering and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	MinnDOT, "Twin Cities Ramp Meter Evaluation - Final Report"	Reports safety impacts of ramp metering	Limited to one city
1999	Upchurch and Cleavenger, "Freeway Ramp Metering's Effect on Accidents: Recent Arizona Experience"	Before and after study of crashes on the mainline and ramps at nine locations in Arizona	Limited to one freeway (two cities) in AZ
1998	MinnDOT, "Trunk Highway 169 - Dynamic Ramp Metering Evaluation"	The study examines changes in accident rates before and after implementation of dynamic ramp metering on a trunk highway in Twin Cities metro area.	Limited to one facility
1998	Jernigan, "Expected Safety Benefits of Implementing Intelligent Transportation Systems in Virginia: A Synthesis of the Literature"	A comprehensive review of studies on the potential safety benefits of ITS including ramp metering; identifies many relevant studies; is not a critical review	Highly relevant literature review; identifies potential resources
1995	Piotrowicz, "Ramp Metering Status in North America	Identified by Jernigan; review of ramp metering in North America; includes assessment of safety benefits	Potential resource
1989	Henry and Meyhan, "Six Year FLOW Evaluation"	Identified by Jernigan; evaluated effect on crash frequency of ramp metering in Seattle, WA	Limited to one city

5.3 SAFETY EFFECTS OF INTERCHANGE SPACING

[Future Edition]

This section will provide information on the safety effect of spacing between interchanges. The relationship between the distance between interchanges and crashes on the facility will be identified. Potential resources include:

- The 1993 Twomey et al. report, "Accidents and Safety Associated with Interchanges", and
- The 1992 Twomey et al. report, "Safety Effectiveness of Highway Design Features. Volume IV: Interchanges".

Both document reviewed past research that studied the effect of interchange spacing on accidents.

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CHAPTER 6: SPECIAL FACILITIES AND GEOMETRIC SITUATIONS

6.1 RAILROAD-HIGHWAY GRADE CROSSINGS

This section will provide information on the safety impact of design elements, traffic control devices, and operational decisions at railroad-highway grade crossings. This section will direct readers to the FHWA publication, "Railroad-Highway Grade Crossing Handbook—Second Edition".

Design Elements

This section will include information on the safety effects of various design elements of railroad-highway grade crossings. The effect of design elements on the crash risk of motor vehicles and pedestrians at the grade crossings will be identified.

If available, the safety effect will be reported as change in crash frequency. Otherwise, the safety effect will be reported as a change in crash surrogates such as compliance. Some design elements will not be included in the first edition of the HSM, but will be included in subsequent editions based on the availability of research to adequately address the topic. These are noted.

> *Editor's Note: The Railroad-Highway Grade Crossing Handbook, Second Edition, includes reviews and of research findings on the safety effect of some design elements at highway grade crossings. Although the publication is slightly outdated (1986), it is a useful starting point for identifying potential resources.*

Illumination

This subsection will address the relationship between crashes at highway-rail grade crossings with illumination versus crashes at grade crossings without illumination.

This subsection will identify the effect of illumination on the crash risk of the grade crossing. A potential resource for this section is the 1991 Mather report, "Seven Years of Illumination at Railroad-Highway Crossings."

Alignment at Crossing [Future HSM edition]

Sight Distance [Future HSM edition]

Proximity of Highway Intersections [Future HSM edition]

Traffic Control and Operations

This section will include information on the safety effect of various traffic control and operational decisions at railroad-highway grade crossings. The effect of traffic control devices and operational choices on the crash risk of motor vehicles and pedestrians at the grade crossings will be identified.

For information on preemption of traffic signals, the reader would be directed to the ITE Recommended Practice, *Preemption of Traffic Signals At or Near Railroad Crossings with Active Warning Devices*.

> *Editor's Note: The author of this chapter should familiarize themselves with NCHRP Synthesis of Highway Practice 271: Traffic Signal Operations Near Highway-Rail Grade Crossings.*

Choice of Advanced Traffic Control at Crossing

The subsection will provide information on the safety effect of various traffic control devices (signs and markings) used in advance of railroad-highway grade crossings. The effect of the crash risk of motorists and pedestrians at the grade crossing will be identified. This subsection will also include information on the safety effect of using pre-signals on the approach.

Traffic Control at Crossing

This subsection will provide information on the safety effect of traffic control devices used to deter vehicles from entering the crossing when a train is approaching. The relative crash risk of intersections without traffic control devices to deter entry, the crash risk of intersections with standard gates, and the crash risk of intersections with quadrant gates will be assessed.

> *Editor's Note: A study is currently underway at TTI on improved traffic control devices at rail-highway grade crossings. Many of their findings to date have been reported in unpublished, working papers. The author of this section should pursue TTI as a source of information on this topic.*

Operational Decisions

The subsection will include information on the safety effect of operational decisions at railroad-highway grade crossings, specifically the use of constant warning time devices at rail-highway grade crossings. Constant warning devices improve the delay to motorists by detecting the speed of the approaching train. At a designated time (e.g. 20 seconds) before the train reaches the crossing, the motorist is warned. This reduces unnecessary delay from slow moving trains or trains that are involved in significant switching movements on the approach. The relative crash risk at rail-highway grade crossings equipped with constant warning time devices as opposed to conventional warning time devices will be addressed in this subsection.

Potential resources on the relationship between advanced traffic control and safety are identified in Table A- 44. Potential resources on the relationship between traffic control devices at railroad crossings are safety are identified in Table A- 45. Potential resources on the safety relationship of operational decisions at railroad crossings are presented in Table A- 46.

Table A- 44: Potential resources on the relationship between advanced traffic control and safety.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
Expected in 2002	*NCHRP Report 470* [Recommended Traffic-Control Devices for Railroad-Highway Grade Crossings]	Includes a detailed critical review of research on the effect of traffic control devices at rail-highway grade crossings; Also evaluated traffic control devices	Comprehensive review when released
2001	Korve et al., "Light Rail Service: Pedestrian and Vehicular Safety", TCRP Report 69	Presents "before and after" evaluation of the safety effect of presignals at highway-rail grade crossings; two locations	Limited to two sites in IL
		Study also reviewed research on materials related to rail-highway crossing safety (pg 133-139)	Identified potential resources
1998	Fambro and Frieslaar, "Highway Traffic Signal Applications at Rail-Highway Grade Crossings", [Working Paper 3]	Includes findings of a before and after crash evaluation of signal installation	Potential resource, results limited to two sites
1989	Fambro et al., "Evaluation of Two Active Traffic Control Devices for Use at Railroad-Highway Grade Crossings"	Before and after study of safety of two separate devices (light-emitting warning device and a traffic signal) using surrogates (e.g. violations)	Potential resource, limited to two sites

Table A- 45: Potential resources on the safety effect of traffic control devices at railroad crossings.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
Expected in 2002	NCHRP Report 470 [Recommended Traffic-Control Devices for Railroad-Highway Grade Crossings]	Includes a detailed critical review of research on the effect of traffic control devices at rail-highway grade crossings; Also evaluated traffic control devices	Comprehensive review when released
1995	LA County MTA, "Evaluation of Pedestrian Swing Gates at the Imperial Highway Station"	Before and after evaluation of pedestrian traffic control at light rail station, used frequency of dangerous ped maneuvers as MOE	Limited to one site, pedestrian safety only
1989	Heathington et al., "Field Evaluation of a Four-Quadrant System for Use at Railroad-Highway Grade Crossings"	Before and after field evaluation of effect on safety; surrogate measures used as MOEs	Potential resource, possibly limited to one site

Table A- 46: Potential resources on the safety relationship of operational decisions at railroad crossings.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1990	Richards et al., "Evaluation of Constant Warning Times Using Train Predictors at a Grade Crossing with Flashing Light Signals"	Before and after study at urban crossing, used surrogates as MOE for safety	Limited to one site
1987	Bowman, "The Effectiveness of Railroad Constant Warning Time Systems"	Analyzed the effect of CWT on motorist violation of the warning system; Analyzed the effect of CWT on crashes using 5 years of crash data.	Potential resource
1986	Bowman et al., "The Safety, Economic and Environmental Consequences of Requiring Stops at Railroad-Highway Crossings"	Performed a cross-sectional study of crash data to determine the safety effect of requiring stops at railroad-highway crossings	Potential Resource

6.2 CONSTRUCTION AND MAINTENANCE WORK ZONE AREAS

This section will identify the safety effect of design elements, traffic control devices, and operational decisions in construction and maintenance work zones. This section will direct the reader to the FHWA publication, "Work Zone Best Practices Guidebook"

Design of Elements of Work Zones

Lane Closure Merge Design

This section will provide information on the safety effect of different lane merge systems used on the approach to work zones to facilitate channeling vehicles into the work zone when the work zone includes a lane closure. Potential resources are identified in Table A- 47.

Closure Design and Centerline Treatments

This subsection will identify the safety effect of various centerline treatments (e.g. double yellow pavement markings or portable concrete barriers) or lane closure designs (e.g. single lane closure versus a crossover with two-lane, two-way traffic operations) in construction and maintenance work zones. The relationship between crashes in work zones with different centerline and lane closure treatments will be addressed. Potential resources are identified in Table A- 48.

Duration, Length, and Time of Day

This subsection will identify the relationship between the duration of a work zone and safety. It will also identify the relationship between the length of a work zone and safety and the time (i.e. day or night) when the work is conducted and safety. Potential resources are identified in Table A- 49.

Other Design Elements

[Future HSM editions]

Table A- 47: Potential resources on the safety effect of lane merge systems and safety in work zones.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	Tarko and Venugopal, "Safety and Capacity Evaluation of the Indiana Lane Merge System"	Before and after study of Indiana Lane Merge System (ILMS), observed conflicts and related to crash reductions	Potential resource, limited in scope
1999	Pesti et al., "Traffic Flow Characteristics of the 'Late Merge' Work Zone Control Strategy"	Reports findings of evaluation of late merge system, conflicts used as surrogate for safety	Potential resource, limited in scope

Table A- 48: Potential resources on the relationship of closure design and centerline treatments and safety in work zones.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
1996	Pal and Sinha, "Analysis of Crash Rates at Interstate Work Zones in Indiana"	Comparative analysis of crash rates at Interstate work zones in Indiana, analyzed relative safety effects of partial lane closure and crossover	Potential resource, limited in scope
1986	Dudek et al., "Some Effects of Traffic Control on Four-Lane Divided Highways"	Evaluated the effect on safety (using crashes and conflicts) of various work zone that used a single lane closure as compared to two-lane, two-way operation; 4-lane divided hwy	Potential resource, limited to nine sites in TX and OK
1983	Graham and Migletz, "Design Considerations for Two-Lane, Two-Way Work Zone Operations"	Cross-sectional study of crashes at 36 divided highway work zones that employed 2-lane, 2-way operation or lane closure; centerline treatments were analyzed	Potential resource

Table A- 49: Potential resources on the relationship between the duration of a work zone and safet.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2002	Khattak, Khattak, and Council, “Effects of Work Zone Presence on Injury and Non-Injury Events”	Used freeway crash data to develop a relationship between crash frequency and the duration, length, and ADT of a work zone	Potential resource
1988	Rouphail et al., “Comparative Study of Short- and Long-Term Urban Freeway Work Zones”	Comparative study of crash experience at long-term and short-term freeway work zones	Potential resource
1988	McCoy and Peterson, “Safety Effects of Two-Lane Two-Way Segment Length Through Work Zones on Normally Four-Lane Divided Highways”	Studied the relationship between work zone segment length and five speed distribution parameters used as surrogates for safety; used four-lane divided highways	Potential resource, limited to Nebraska

Operations and Traffic Control

This section will include information on the safety effect of traffic control devices and operational decisions in work zones.

Speed Control in Work Zones

The speed of vehicles traveling through a work zone can be used as a surrogate for the safety of the work zone. This subsection will address the effectiveness of traffic control devices and operational decisions that affect the operating speed of vehicles in work zones. The effectiveness of changeable message signs in regulating the speeds will be addressed. Potential resources are identified in Table A- 50.

Traffic Control Devices

This subsection will provide information on the safety effectiveness of various work zone traffic control devices including flaggers, construction barrels, flashing arrows, and static signs. Potential resources are identified in Table A- 51.

Table A- 50: Potential resources on the relationship of speed control and safety in work zones.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	Bernhardt et al., "Evaluation of Supplementary Traffic Control Measures for Freeway Work-Zone Approaches"	Evaluated (unknown design) 3 speed control measures in interstate work zone in MO	Potential resource, limited to Interstates in MO
1998	Garber and Srinivasan, "Effectiveness of Changeable Message Sign in Controlling Vehicle Speeds in Work Zones"	Used a before and after study to evaluate the effect of CMS on vehicle speed in 7 work zones on two interstates in VA	Potential resource, limited to two interstates in VA
1994	Freedman et al., "Effect of Radar Drone Operation on Speeds at High Crash Risk Locations"	Reports findings of a before and after study on the effect of drone radar at 12 work zones (and high crash locations) in Missouri (unknown func. class)	Potential resource, limited to MO
1993	McCoy and Bonneson, "Work Zone Safety Device Evaluation"	Identified effective traffic control devices in work zones and conducted before and after field evaluations of speed reducing potential of rumble strips on rural 2-lane	Limited to work zones in South Dakota, may identify other potential sources
1985	Richards et al., "Improvements and New Concepts for Traffic Control in Work Zones"	Evaluated four work zone speed reduction measures; studies conducted on an undivided multilane urban arterial, an urban freeway, and two rural freeways; reports results from 2-lane rural highway also	Potential resource
1977	Graham et al., "Accident and Speed Studies in Construction Zones"	Evaluated safety (conflicts, erratic maneuvers, and speed) of various tcd in work zones at 3 sites—an urban freeway, rural freeway, urban street	Potential resource although over 25 years old

Table A- 51: Potential resources on the safety effectiveness of traffic control devices in work zones.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2001	Fontaine and Hawkins, “Catalog of Effective Treatments to Improve Driver and Worker Safety at Short-Term Work Zones”	Provides the results of evaluations of various traffic control devices used in short-term work zones; surrogates used to evaluate safety	Potential resource; not all results are quantitative
1999	Walker and Upchurch, “Effective Countermeasures to Reduce Accidents in Work Zones”	Reviews the effectiveness of countermeasures throughout the country at reducing crashes in work zones	Identifies potential resources
1991	Garber and Woo, “Effectiveness of Traffic Control Devices in Reducing Accident Rates at Urban Work Zones”	Used crash data in urban work zones to develop regression models that relate crash rates to types of traffic control devices	Limited to sites in VA
1991	Garber and Woo, “Effectiveness of Traffic Control Devices in Reducing Accident Rates at Urban Work Zones”	Used crash data in urban work zones to evaluate traffic control devices including temporary pavement markings; two-lane and multi-lane highways in VA	Limited to sites in VA
1990	Rouphail et al., “Freeway Construction Zones in Illinois: A Follow-Up Study”	Evaluated the effect of traffic control device measures in freeway work zones on crash rates	Limited to three sites on one facility
1988	Dudek, “Field Studies of Temporary Pavement Marking at Overlay Work Zones on Two-Lane, Two-Way Rural Highways”	Evaluated the safety effectiveness of 1, 2, and 4 ft broken line pavement markings in work zones in AK, CO, OK, and TX; two-lane, rural	Potential resource

6.3 BRIDGES

(Future HSM Edition)

6.4 HIGH OCCUPANCY VEHICLE (HOV) LANES/FACILITIES

(Future HSM Edition)

6.5 TUNNELS

(Future HSM Edition)

6.6 REVERSIBLE LANES

(Future HSM Edition)

6.7 WEAVING AREAS, COLLECTOR-DISTRIBUTOR ROADS, AND FRONTAGE ROADS

(Future HSM Edition)

6.8 TRANSIT FACILITIES AND RELATED FEATURES

(Future HSM Edition)

6.9 BICYCLE AND PEDESTRIAN FACILITIES AND RELATED FEATURES

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CHAPTER 7. ROAD NETWORKS

After the chapter about roadway segments, the chapter about intersections and interchanges, and the chapter about other facilities, the next logical chapter is one about Networks dealing with the integration of segments, intersections and other facilities. Consequently, the intent was to devote a chapter to safety information for those who plan the future transportation network (on a state, metropolitan, or neighborhood level) and those who operate a network of interdependent facilities (e.g., one-way systems, turn restrictions and traffic calming).

However, as will be intimated below, some of the knowledge proposed for chapter 7 will also, sooner or later, have predictive methods associated with it. Therefore, consideration should perhaps be given to a placeholder in Part III. That is, saving space for Chapter 10, to be entitled “Predictive Methods for Safety in Networks.”

7.1 INTRODUCTION

In the earlier chapters, the focus was on the effect of design and operational decisions on the safety of roadway segments, intersections, interchanges, and other facilities (e.g., grade crossings, bridges or tunnels). Taken together, these elements (i.e., segments, intersections, interchanges, other facilities), form an interdependent road network on which travel takes place. In some cases (e.g., shoulder widening or provision of a turn lane), one may assume that the travel pattern is only slightly affected by design and operational decisions. In other cases, such an assumption lacks realism. Thus, for example, even if one only restricted left-turns at an intersection (thereby affecting its future safety), the restricted turns will materialize elsewhere on the network. Therefore, it is insufficient to consider the safety impact of the turn restriction only on intersection where it is to be implemented. Similar interdependencies exist when designing one-way street systems, when a neighborhood traffic calming system is considered, and when deciding on an interchange location, among other items. That is, whenever a design or operational decision affects the mode, route, or trip choice of users, the focus must shift from the consideration of a single element to the consideration of the affected network and the pattern of trips on it.

The need for integration is even more evident when it comes to transportation planning. From the earlier perspective of road design and traffic operational decisions it was useful to parse safety knowledge into chapters such “Segments” or “Intersections” and to discuss safety within elementary compartments such as the effect of Lane Width, Grade, Inter-Green or Speed Zoning on safety. From the transportation planning perspective, this atomic representation is of little interest. What is necessary is knowledge of the safety effect of the kind of decisions that are made in the course of planning.

The impact of planning decisions on future road safety is of paramount importance. How far people travel in the course of their daily activities, whether they take the train, subway, bus, car or walk, whether they travel on the safer freeway or the less safe arterial, whether they pass few large-volume intersections or many lesser volume intersections, whether children need to cross roads on their way to schools, whether the local road is a crescent or a cul-de-sac, are all results of planning decisions. In short, the number of crashes by severity expected to occur in the future is determined mainly by planning decisions: how much travel will take place, by what mode, and on what kind of facility.

The main purpose of this chapter is to present what knowledge is available to facilitate the consideration of the safety impact of those design, operational and planning decisions that affect the amount of travel, the mode of travel and the facility on which travel takes place so that their safety impact must be traced to a part of a transport network.

The interdependencies that affect safety come about not only by the unity of the transportation network that accommodates travel by a variety of modes and facilities, but also by the unity of road user behavior that is best called a road-use culture. Road-use culture characterizes a society and a region. Our actions affect road-use culture even when the action itself is localized in nature. Thus, e.g., installing red-light cameras at selected intersections is likely to affect behavior at other intersections as well; the use of several all-way stops in a neighborhood will create the expectation that this mode is used at the next intersections, etc. Even if little is know at present about the relationship between what we do and how road-use culture evolves, one section of this chapter will be devoted to this topic.

7.2 SAFETY IN TRANSPORTATION NETWORK PLANNING

Transportation-land-use planning exercises are complex and diverse. However, common to all is the examination of the performance of proposed alternative transportation networks in the light of demographic, land-use and trip making forecasts. The suitability of a proposed network is usually assessed in terms of its future cost, travel time, energy consumption, environmental amenity, etc. Future safety ought to be one of the yardsticks by which proposed transportation network is assessed. To produce an estimate of future safety performance of a proposed transportation network should be relatively simple. Since forecasts of travel by mode, type of facility, and even route are routinely produced, all one needs to know is how many accidents by severity are expected to materialize every year as a function of the forecast amount of travel by mode, facility, and route. Accordingly, this section will attempt to provide the necessary information. The requisite information may be of the aggregate kind (e.g., the characteristic safety performance functions by mode, and by kind of facility). The disaggregate information is also useful in ascertaining the safety impact of locating ‘major attractors’ such as sports stadiums, truck terminals, and the like.

Transportation network planning is guided not only be demographic and land-use forecasts but also by planning principles. What matters to safety are mainly the principles related to spacing and density of freeways and of arterials (and the related spacing and size of interchanges and intersections). Accordingly, this section will contain information about how safety depends in the hierarchy and density of roads and intersections.

7.3 SAFETY IN THE PLANNING AND DESIGN OF RESIDENTIAL NEIGHBORHOODS AND COMMERCIAL AREAS

Most of the road network around us did not exist when we were born. Much of it evolved not as a result of (or in accord with) a long-range plan but through a series of additions and alterations; a subdivision here, a new shopping complex there. Thus, most accidents (at least in urbanized areas) occur on facilities that are not shaped within some deliberate long-term planning exercise. They materialize through the initiative of developers, within the constraints of municipal supervision, and through the professional activities of architects, engineers and surveyors. For the interest of safety to be reflected in the decisions of these professionals (within the context of planning and design of residential neighborhoods and commercial areas) they must have the appropriate information.

The safety considerations in the planning and design of residential neighbourhoods has to do with the safety performance of various types of collector roads (e.g., crescents, grids, cul-de-sacs, etc.), average distance to arterials, the density and type of intersections, accommodation of school children and other pedestrians etc. The safety considerations in the planning and design of commercial areas have to do with the design of internal circulation, parking lots and of the type and location of access to the arterial network.

7.4 ONE-WAY SYSTEMS AND TURN RESTRICTIONS

The introduction of a one-way system affects speed, pedestrian crossings and intersection operations on the converted streets. It also tends to prolong trip length, and affect volume and turns in neighboring areas. There are the items of information to be covered, in addition to whatever is known about the safety effect of introducing one-way schemes.

The effect of a turn restriction is to shift travel from one place to another. The information to be covered are the typical safety consequences on left and right turns (under varying circumstances and volumes) and also the safety consequences of adding new flow to an existing one.

7.5 SAFETY IN TRAFFIC CALMING

Various measures are used in traffic calming: turn restrictions, speed bumps, intersection elevation, and paving textures, among other items. There has been some evaluation of the global safety effect of traffic calming and of some of the measures of which it consists (e.g., speed bumps). This section will be devoted to such information.

7.6 ACCESS MANAGEMENT

Access management is a set of techniques to limit conflict points due to access, to separate conflict areas or to remove vehicles from the through lane. This section will provide information on the safety cost of access by residential and commercial driveways and intersections, and on the safety effect of various access management techniques (e.g., prevention of left-turn by barriers and other median dividers, offsetting and aligning driveways, etc.).

Table A- 52: Potential resources on the safety effect of various access management techniques.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
Accessed March, 2002	"Access and Safety", Unpublished Literature Review by Dr. Ezra Hauer, located at: www.roadsafetyresearch.org	Critical review of literature on the safety effects of intersection spacing	Comprehensive, Critical Review of intersection spacing
2000	Papayannoulis et al., "Access Spacing and Traffic Safety"	Reviews research studies that relate traffic safety to access spacing; analyzes data from 8 states; provided input for NCHRP Report 420	Potential resource, possibly redundant with NCHRP 420
1999	"Impacts of Access Management Techniques", NCHRP Report 420	Provides the results of numerous research studies on the safety impacts of various access management techniques	Comprehensive review of many techniques
1997	Levinson and Gluck, "Safety Benefits of Access Spacing"	Reviews various studies that identified the safety benefits of access spacing	Identifies potential sources
1996	Miaou, "Measuring the Goodness of Fit of Accident Prediction Models"	Estimated a multivariate model of intersection spacing and safety	Identified by Hauer as critical literature
1996	Gattis, "Comparison of Delay and Accidents on Three Roadway Access Designs in a Small City"	Compared crash rates of three corridors with various types of access management; small city	Limited to three corridors in one city
1993	Long et al, "Safety Impacts of Selected Median and Access Design Features"	Cross-sectional evaluation of effect of medians and driveway density on crashes on urban arterials; 400 miles of urban roads in FL	Potential resource; limited to FL
1982	"Access Management for Streets and Highways"	Compiles predictions of crash reduction potential	Potential resource

This section should also include discussion on the role that access management plays in maintaining network hierarchy. Access management serves operational and safety functions by directing access to the local and collectors to maintain the mobility function of the arterial.

With respect to specific items under the broad category of access management, the author should devote sufficient time to the discussion of this topic within the context of roadway network. The author should recognize that access management has a local connotation with respect to specific issues. The author may wish to consider whether some of the material presented in this discussion should be also included or cross-referenced or moved entirely to Chapter 3, Roadway Segments, or Chapter 4, Intersections. For the purposes of this initial outline, all access management-related items are recommended for this section.

Access Point Elements

This section will identify the effect that access points on roadway segments have on the safety of the roadway segment.

Access Point Density

This subsection will identify the effect that the density of access points (e.g., driveways, median openings, very minor intersections) has on the safety of a roadway segment. The section should clearly define what defines an access point and what differentiates an access point from an intersection.

Research on rural two-lane highways for the corresponding Analytical Methods Chapter in Part III identified the relationship between vertical alignment and safety as reported in *Prediction of the Expected Safety Performance of Rural Two-Lane Highways*. Access point density is accounted for by the density of driveways on a roadway segment. For the base model, 3 driveways per kilometer (5 driveways per mile) was the nominal condition. This can be modified with a crash reduction factor that combines driveway density and ADT. As the density increases over five driveways per mile, the crash risk increases. For segments with less than the five driveways per mile, the crash risk decreases.

Table A- 53 identifies some potential resources on the relationship between access point density and safety on urban and suburban arterials.

Other Access Point Elements

This subsection should identify the safety effects of other access point elements such as the type of access points (e.g. commercial versus residential) and the design of those access points.

Table A- 53: Potential resources on the relationship between access point density and safety on urban and suburban arterials.

YEAR	DOCUMENT	DESCRIPTION	COMMENT
2000	Papayannoulis et al., "Access Spacing and Traffic Safety"	Reviews studies that relate safety to access spacing. Conducted analyses of crash data and access spacing; data from eight states; urban and rural analyzed separately	Highly relevant resource; identifies other studies
1995	Lall et al., "Analysis of Traffic Accidents within the Functional Area of Intersections and Driveways"	Analyzed 29 miles of Oregon Coast Highway; considered effect of access spacing in both urban and rural areas	Identified by Papayannoulis; potential resource
1997	McLean, "Practical Relationships for the Assessment of Road Feature Treatments"	Analyzed effect of access spacing on crashes in Australia; urban and rural considered separately	Identified by Papayannoulis; potential resource

7.7 ROAD-USE CULTURE

The culture of road-use is reflected in choices people make about speed, about yielding to pedestrians, about whether to enter intersections on amber or red, whether to tailgate, when to pass or accept a gap in traffic etc. There is perhaps little substantive knowledge that can be placed in this section now. The hope is that, as knowledge expands, it will find its repository in this section.

The reader will be directed to the FHWA publication, "Safety Effectiveness of Highway Design Elements. Volume I: Access Control" and the ITE informational report, "Access Management – A Key to Safety and Mobility".

7.8 URBAN COMMERCIAL AREAS

(Future HSM Edition)

7.9 TRANSITIONS BETWEEN HIGHWAY FACILITY TYPES

(Future HSM Edition)

It is highly desirable that this section be developed as soon as possible. If and when the decision is made to develop material for this section, it is emphasized that the section cover the following two topics, at a minimu:

- Continuity of network elements.

- Safety Effects of Network Discontinuity. (e.g., overlapping routes)

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PART III – PREDICTIVE METHODS

Editor's Note: The desire in Part III would be to have linkages to interactive tools that have already been developed in areas such as pedestrian safety. For example, there may be a linkage to the FHWA Pedestrian/Bicycle Safety Resource Set.

CHAPTER 8. RURAL, TWO-LANE ROADS

8.1 INTRODUCTION

Section 1 provides a brief introduction of the scope and limitations of the safety prediction methodology for two-lane highways.

8.1.1 Scope of the Methodology

The objective of the safety prediction methodology is to quantify the safety performance measures for an existing or proposed two-lane highway facility operating under current or projected traffic demand. The primary safety performance measure for two-lane highways is the expected annual accident frequency.

8.1.2 Limitations of the Methodology

The methodology is based on the current state of knowledge concerning the safety effects of two-lane highway features. The methodology should be updated as new research results become available. A key limitation of the methodology is the treatment of the effects of individual geometric design and traffic control features as independent of one another.

8.2 METHODOLOGY

Section 2 defines and formulates base models, AMFs, and calibration factors and documents the safety prediction methodology for roadway segments, for three types of at-grade intersections, and for an entire project.

8.2.1 Overview of the Safety Prediction Methodology

Section 2.1 provides an overview of when and with what type of projects the safety prediction methodology should be used. The discussion introduces the general formulations to predict accidents for roadway segments, at-grade intersections, and entire projects, which are used and referenced throughout the chapter.

8.2.1.1 Structure of the Safety Prediction Methodology

This section introduces the structure of the safety prediction methodology, composed of base models, calibration factors, and accident modification factors (AMFs).

8.2.1.1.1 Base Models

A base model is a regression model that predicts the total accident frequency of roadway segments or intersections on two-lane highways for nominal conditions.

8.2.1.1.2 Accident Modification Factors

Accident modification factors (AMF) are multiplicative factor used to adjust the base model predictions for the effects of individual geometric design and traffic control features.

8.2.1.2 Calibration of the Methodology to Local Conditions

This section provides an overview of the procedures for calibrating the methodology to local conditions by quantifying a calibration factor that is used in the safety prediction methodology.. The details of the calibration procedure are presented in Appendix A.

8.2.1.3 Roadway Segments

This section provides an overview of the safety prediction methodology for roadway segments.

8.2.1.4 At-Grade Intersections

This section provides an overview of the safety prediction methodology for at-grade intersections.

8.2.1.5 Safety Prediction for Entire Projects

This section describes how the safety predictions for individual roadway segments and at-grade intersections can be combined to obtain a safety prediction for an entire project.

8.2.1.6 Accident Severity and Accident Type Distribution

This section introduces the default values of accident severity and accident type distributions for roadway segments and at-grade intersections that are used to estimate accident severities and types for specific sites. A description on how to replace these default values with data suitable for the two-lane highway system of a particular highway agency is presented in Appendix A.

8.2.2 Safety Prediction Methodology for Roadway Segments

Section 2.2 presents the methodology for predicting safety for roadway segments.

***Editor's Note**: The FHWA is currently reexamining the accident modification factors for horizontal curves and vertical grades and curves. Additionally, they are reexamining the use and guidance of the Empirical Bayes method. The new work is expected to be done in Fall 2002.*

8.2.2.1 Base Model for Roadway Segments

The base model for roadway segments is presented in this section. This base model is a negative binomial regression equation that incorporates the effect of average daily traffic (ADT) volume on the predicted accident frequency for roadway segments, as well as nominal values for selected geometric design and traffic control features.

8.2.2.2 Accident Modification Factors for Roadway Segments

The AMFs represent the incremental effect of individual geometric design and traffic control features of roadway segments in the safety prediction model. The development of the AMFs combines historical accident data, regression analysis, before-and-after studies, and expert judgment. The AMFs for each individual geometric design and traffic control feature of roadway segments are shown in the following subsections:

8.2.2.2.1 Lane Width

8.2.2.2.2 Shoulder Width and Shoulder Type

8.2.2.2.3 Horizontal Curves

8.2.2.2.4 Grade

8.2.2.2.5 Driveway Density

8.2.2.2.6 Passing Lanes

8.2.2.2.7 Two-Way Left-Turn Lanes

8.2.2.2.8 Roadside Design

8.2.2.3 Methodology for Determining the Expected Accident Frequency for a Particular Roadway Segment

This section presents the nine steps that are followed to calculate the expected accident frequency for a particular roadway segment. The steps include the obtaining the required input data; determining of the Adds for each year of analysis; use of the base model, calibration factors, AMFs; use of the expected distribution of accident severities and accident types; and the computation of the predicted accident frequency for an individual roadway segment.

8.2.3 Safety Prediction Methodology for At-Grade Intersections

Section 2.3 presents the methodology for predicting safety for roadway segments.

8.2.3.1 Base Model for At-Grade Intersections

The base models for at-grade intersections are presented in this section. Separate base models are provided for specific types of intersections (three-leg intersections with stop control, four-leg intersections with stop control, and four-leg intersections with signal control). These equations incorporate the effect of average daily traffic (ADT) volume on the predicted accident frequency for at-grade intersections, as well as nominal values for selected geometric design and traffic control features.

8.2.3.1.1 Three-Leg Stop-Controlled Intersections

8.2.3.1.2 Four-Leg Stop-Controlled Intersections

8.2.3.1.3 Four-Leg Signalized Intersections

8.2.3.2 Accident Modification Factors for At-Grade Intersections

The AMFs represent the incremental effect of individual geometric design and traffic control features of at-grade intersections in the safety prediction model. The development of the AMFs combines historical accident data, regression analysis, before-and-after studies, and expert judgment. The AMFs for each individual geometric design and traffic control feature of at-grade intersections are shown in the following subsections:

8.2.3.2.1 Skew Angle

8.2.3.2.2 Traffic Control

8.2.3.2.3 Exclusive Left-Turn Lanes

8.2.3.2.4 Exclusive Right-Turn Lanes

8.2.3.2.5 Intersection Sight Distance

8.2.3.3 Methodology for Determining the Expected Accident Frequency for a Particular At-Grade Intersection

This section presents the nine steps that are followed to calculate the expected accident frequency for a particular at-grade intersection. The steps include the obtaining the required input data; determining of the ADTs for each year of analysis; use of the base model, calibration factors, AMFs; use of the expected distribution of accident severities and accident types; and the computation of the predicted accident frequency for an individual intersection.

8.2.4 Safety Prediction Methodology for an Entire Project

This section describes how accident frequency can be predicted for an entire project, composed of a series of homogeneous roadway segments and intersections to which the methodologies presented in Sections 2.2 and 2.3 are applied.

8.3 APPLICATIONS

Section 3 presents a detailed description of the computation steps of the safety prediction methodology.

8.3.1 Safety Prediction When Site-Specific Accident History Data are not Available

This section outlines the computational steps presented in Sections 2.2, 2.3, and 2.4 and three worksheets to estimate the expected accident frequency for roadway segments, at-grade intersections, and entire projects when site specific accident history are not available.

8.3.1.1 Roadway Segments

8.3.1.2 At-Grade Intersections

8.3.1.3 Entire Projects

8.3.2 Safety Prediction When Site-Specific Accident History Data are Available

This section outlines the changes in the methodology when site-specific accident history data are available. The primary change is that the methodology incorporates an Empirical Bayes (EB) procedure that is presented in detail in Appendix B. Section 3.2 includes a discussion of situations in which this EB procedure should and should not be applied.

8.4 EXAMPLE PROBLEMS

Six representative example problems are solved using the computation steps and worksheets presented in Sections 2 and 3. Examples 1 and 2 illustrate how to calculate the accident frequency per year for two cases of two-lane roadway segment. Example 1 addresses a tangent segment and Example 2 addresses a horizontal curve. Examples 3 and 4 illustrate how to estimate the accident frequencies for a three-leg stop-controlled intersection and a four-leg signalized intersection. Examples 5 and 6 illustrates how to estimate the accident frequency for an entire project that, in this case, is comprised of the two roadway segments and two intersections addressed in Examples 1 through 4. Example 5 addresses the case when no site-specific accident history data are available. Example 6 addresses the application of the EB methodology when site-specific accident history data are available.

8.4.1 Example 1 (Tangent Roadway Segment)

8.4.2 Example 2 (Curve Roadway Segment)

8.4.3 Example 3 (Three-Leg Stop-Controlled Intersection)

8.4.4 Example 4 (Four-Leg Signalized Intersection)

8.4.5 Example 5 (Entire Project with No Site-Specific Accident History Data Available)

8.4.6 Example 6 (Entire Project with Site-Specific Accident History Data Available)

8.5 REFERENCES

APPENDICES

Appendix A - Calibration Procedure

This appendix describes the purpose and application of the recommended calibration procedure for use with the safety prediction methodology. This appendix addresses the calibration procedure for roadway segments, at-grade intersections, the default accident severity distribution, and the default accident type distribution.

Appendix B - Safety Prediction When Site-Specific Accident History Data are Available - EB Procedure

This appendix presents the EB procedure and illustrates its application in the safety prediction methodology.

Appendix C - Definitions of Roadside Hazard Ratings Used with the Safety Prediction Methodology

This appendix presents the roadside hazard rating system developed by Zegeer et al. to characterize the accident potential for roadside designs found on two-lane highways.

CHAPTER 9. RURAL, MULTI-LANE HIGHWAYS

9.1 INTRODUCTION

9.2 METHODOLOGY

Overview of the Crash Prediction Algorithm

Structure of the Crash Prediction Algorithm

Calibration of the Algorithm to Local Conditions

Roadway Segments

At-Grade Intersections

Predicted Crash Frequency for an Entire Project

Roadway Segments

Base Model

Calibration Factors

Crash Modification Factors

Lane width

Shoulder width and type

Horizontal alignment

Vertical Alignment

Median design

Driveway and other access point density

Two-way left-turn lanes

Roadside design

At-Grade Intersections

Base Models

Three-leg STOP-controlled intersections

Four-leg STOP-controlled intersections

Four-leg signalized intersections

Calibration Factors

Crash Modification Factors

Skew angle

Traffic control

Exclusive left-turn lanes

Exclusive right-turn lanes

Intersection sight distance

9.3 PROCEDURES FOR APPLICATION

Crash Prediction when Site-Specific Crash History Data Are Not Available

Crash Prediction when Site-Specific Crash History Data Are Available

Situations in Which the EB Procedure Should and Should Not Be Applied

Empirical Bayes (E-B) Procedure

9.4 SAFETY ISSUES NOT EXPLICITLY ADDRESSED BY THE METHODOLOGY

9.5 SAMPLE CALCULATIONS

Example 1 – Crash prediction when site-specific crash history data are not available

Example 2 – Application of the E-B procedure

Example 3 – Crash prediction when site-specific crash history data are available

Other examples (to illustrate variations in the methodology)

9.6 SOFTWARE FOR PERFORMING CALCULATIONS

9.7 REFERENCES

APPENDICES

Worksheets for Use in Analysis of Multi-lane Highways

Supporting Material (related material for use in HSM Part II)

CHAPTER 10. URBAN AND SUBURBAN ARTERIAL HIGHWAYS

10.1 INTRODUCTION

10.2 METHODOLOGY

Overview of the Crash Prediction Algorithm

Structure of the Crash Prediction Algorithm

Calibration of the Algorithm to Local Conditions

Roadway Segments

At-Grade Intersections

Predicted Crash Frequency for an Entire Project

Roadway Segments

Base Model

Calibration Factors

Crash Modification Factors

Lane width

Shoulder width and type

Curb design

Horizontal alignment

Vertical alignment

Median design

Driveway and other access point density

Two-way left-turn lanes

Roadside design

At-Grade Intersections

Base Models

Three-leg STOP-controlled intersections

Four-leg STOP-controlled intersections

Three-leg All-way Stop controlled intersections

Four-leg All-way Stop Controlled intersections

Three-legged signalized intersections

Four-leg signalized intersections

Calibration Factors

Crash Modification Factors

Skew angle

Traffic control

Exclusive left-turn lanes

Exclusive right-turn lanes

Intersection sight distance

10.3 PROCEDURES FOR APPLICATION

Crash Prediction when Site-Specific Crash History Data Are Not Available

Crash Prediction when Site-Specific Crash History Data Are Available

Situations in Which the EB Procedure Should and Should Not Be Applied

Empirical Bayes (E-B) Procedure

10.4 SAFETY ISSUES NOT EXPLICITLY ADDRESSED BY THE METHODOLOGY

10.5 SAMPLE CALCULATIONS

Example 1 – Crash prediction when site-specific crash history data are not available

Example 2 – Application of the E-B procedure

Example 3 – Crash prediction when site-specific crash history data are available

Other examples (to illustrate variations in the methodology)

10.6 SOFTWARE FOR PERFORMING CALCULATIONS

10.7 REFERENCES

APPENDICES

Worksheets for Use in Analysis of Urban and Suburban Arterials

Supporting Material (related material for use in HSM Part II)

Editor's Note: Future Editions may include the following chapters:

- *Rural Freeways*
- *Urban and Suburban Collector and Local Streets*
- *Urban and Suburban Freeways and Expressways*

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PART IV – SAFETY MANAGEMENT OF A ROADWAY SYSTEM

The literature for Part IV was based largely upon the following sources and should be acknowledged.

- Federal Highway Administration (FHWA) study, entitled "Comprehensive Highway Safety Improvement Model", FHWA contract number DTFH61-00-C-00072.
- Comprehensive Highway Safety Improvement Model (CHSIM), by Mr. Michael S. Griffith, FHWA R&D, July 30, 2001 presentation.
- "Applying The Science Of Highway Safety To Effect Highway Improvements–A Multi-Disciplinary Approach, by Bhagwant Persaud - Ryerson Polytechnic University; Geni Bahar –Delcan Corporation; Alison Smiley -Human Factors North; Ezra Hauer -University of Toronto; Jim Proietti -Ministry of Transportation, Ontario; versions of this paper presented at the Canadian Multidisciplinary Road Safety Conference XI; May 9-12, 1999; Halifax, Nova Scotia and at the Canadian ITE Meeting in Montreal Quebec in April 1999. (Referenced as part of the Federal Highway Administration (FHWA) study, entitled "Comprehensive Highway Safety Improvement Model", FHWA contract number DTFH61-00-C-00072).
- Screening for Sites with Promise- Working Paper 9, by Ezra Hauer, January 3, 2000. (Referenced as part of the Federal Highway Administration (FHWA) study, entitled "Comprehensive Highway Safety Improvement Model", FHWA contract number DTFH61-00-C-00072).

It is emphasized that the author of this section should present information on methods as alternatives. Moreover, multiple methods should be clearly documented.

PURPOSE

The overall goal is to identify accident locations within the transportation system, then select cost-effective safety improvements to be implemented based on best value to available resources. To do this, a useful and effective safety management program is essential if better safety decisions are to be made.

Recognizing this need, the Federal Highway Administration (FHWA) and the Federal Motor Carrier Safety Administration (FMCSA) initiated the development of the Comprehensive Highway Safety Improvement Model (CHSIM) project. The intent of the project, to improve the safety of the nation's existing highways, by assisting state and local highway agencies, through upgrading highway safety improvement programs they managed. Specifically, the effort would assist agencies through the development and implementation of a set of innovative analytical tools, designed to guide the process of allocating resources for safety improvements. For this reason, the process described here in PART IV of the HSM is based largely upon the CHSIM concept.

BACKGROUND

The vision for the safety management system is to develop and promote state-of-the-art analytical tools for use in the decision making process, to identify and manage a system-wide program of site-specific improvements and to enhance highway safety by cost-effective means within available funding resources.

The safety management system: 1) addresses site-specific improvements based on site-specific needs, not general programs like vehicle design improvements, occupant restraints, etc. 2) uses state-of-the-art technologies/methodologies to advance the state of the practice 3) is intended to be comprehensive, including all stages of the safety management process 4) is to be rigorous enough to have scientific merit, yet flexible enough to fit into diverse highway agency operating environments 5) draws upon knowledge and experience from other ongoing initiatives and 6) will become PC-based software to help agencies move away from legacy mainframe systems for safety management.

The concept process is based on a set of analytical tools to improve certain steps of the highway safety improvement programs, pertaining to the allocation of resources to achieve the greatest effect in terms of accident frequency and severity reduction on existing highways. These five steps include:

- Identification of "sites with promise"
- Diagnosis of the nature of safety problems at specific sites
- Selection of countermeasures to reduce accident frequency and severity at specific sites
- Economic appraisal of all sites under consideration
- Prioritize rankings of improvement projects

The current practice for each step of the above process is described in the following respective chapter. Overall, this process is expected to achieve significant gains in safety since highway agencies will be relying on better analysis methods/tools to guide their investment strategy. For specific application of the safety management process described here, the reader is directed to the Federal Highway Administration (FHWA) study, entitled "Comprehensive Highway Safety Improvement Model", FHWA contract number DTFH61-00-C-00072.

CHAPTER 11. IDENTIFICATION OF SITES WITH PROMISE

The first step in the safety management process is to evaluate the transportation network and identify accident sites. This screening of the roadway network is intended to identify areas that may have safety concerns. The screening is based on three principles:

- Use expected safety performance and actual accident history to review sites.
- Identify “sites with promise” in reducing accidents in a cost-effective manner
- Review the entire roadway system or selected parts (roadway segments, intersections, ramps, railroad grade crossings, etc.)

The hallmark of the screening process is that it uses data that are routinely electronically stored and can be relatively easily retrieved. The data based on accident information systems and highway inventory management systems (road sections, intersections, traffic flows, etc.) are applied to a defined highway classification system. These data bases must be linked together so that accidents and traffic flow data can be assigned to roadway sections and intersections.

The application of the above screening methodology should result in a list of potential most promising cost-effective safety improvement sites. For specific application of this step of the safety management process described here, the reader is directed to the Federal Highway Administration (FHWA) study, entitled “Comprehensive Highway Safety Improvement Model”, FHWA contract number DTFH61-00-C-00072.

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CHAPTER 12. DIAGNOSIS OF THE NATURE OF SAFETY PROBLEMS AT SPECIFIC SITES

The diagnosis step of the safety management process aims to develop an understanding of the nature of the problem. It is not sufficient to know that there is potential for improvement at a location. It is also necessary to maximize the potential in terms of effectiveness and cost of possible improvements. The diagnosis step is based on five principles:

- Consider sites with promise identified by network screening tool and other sources
- Identify accident patterns
- Investigate causal factors
- Consider site conditions and safety performance from engineering and human factors viewpoints
- Assess whether a potentially correctable safety concern exists

The diagnostic step includes gathering collision diagrams, using police reports, assembling plans and information on traffic volumes and land use, etc. The assessment should include a review of the actions road users were engaged in at the time of collisions, for example left turns or merging, and observing traffic operations, in order to understand the difficulties involved which may have contributed to the collisions. For specific application of this step of the safety management process described here, the reader is directed to the Federal Highway Administration (FHWA) study, entitled "Comprehensive Highway Safety Improvement Model", FHWA contract number DTFH61-00-C-00072.

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CHAPTER 13. SELECTION OF COUNTERMEASURES TO REDUCE ACCIDENT FREQUENCY AND SEVERITY AT SPECIFIC SITES

The development and selection of appropriate countermeasures is a step in the safety management process. The aim is to develop countermeasures to those safety problems identified that apparently lead to the accident(s). The selection of countermeasures step is based on three principles:

- Develop countermeasures that are potentially appropriate for identified accident patterns and safety concerns
- Final selection
- Where appropriate, select a combination of countermeasures and alternative countermeasures for economic appraisal and priority ranking

The results of this step should guide the selection of better safety investment strategies. For specific application of this step of the safety management process described here, the reader is directed to the Federal Highway Administration (FHWA) study, entitled "Comprehensive Highway Safety Improvement Model", FHWA contract number DTFH61-00-C-00072.

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CHAPTER 14. ECONOMIC APPRAISAL OF ALL SITES UNDER CONSIDERATION

This step in the safety management process evaluates the expected site-specific benefits and costs associated with the proposed safety improvements. This appraisal process is based on the four principles:

- Assess expected project benefits
- Assess expected project costs
- Display results
- Provide economic analysis and ranking compatible with Highway Safety Improvement Program (HSIP) requirements

At the completion of this step, the relative merits of a site improvement are determined based on a cost-effectiveness approach. Since the economic analysis is compatible with HSIP requirements, each site is ranked accordingly and can prioritized in the next step of the safety management process. For specific application of this step of the safety management process described here, the reader is directed to the Federal Highway Administration (FHWA) study, entitled "Comprehensive Highway Safety Improvement Model", FHWA contract number DTFH61-00-C-00072.

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CHAPTER 15. PRIORITIZE RANKINGS OF IMPROVEMENT PROJECTS

The final step in the safety management process is to prioritize the ranking of candidate safety improvement projects. To do this, the two basic principles are considered:

- Ranking by economic appraisal results applying:
  - ✓ Cost effectiveness ($/accident reduced)
  - ✓ Benefit-cost ratio (B/C)
  - ✓ Net present benefits (B-C)
- Project selection to maximize safety benefits within a budget constraint
  - ✓ Integer programming
  - ✓ Dynamic programming
  - ✓ Incremental B/C ratio

This final step of the safety management process results in the identification of potential projects prioritized according to cost-effectiveness of proposed improvements. These potential safety improvement projects can then be considered within budget allocations available under the Highway Safety Improvement Program. For specific application of this step of the safety management process described here, the reader is directed to the Federal Highway Administration (FHWA) study, entitled "Comprehensive Highway Safety Improvement Model", FHWA contract number DTFH61-00-C-00072.

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PART V – SAFETY EVALUATION (INCLUDE ALTERNATIVES)

CHAPTER 16. OVERVIEW OF ESTIMATING THE SAFETY EFFECT OF IMPLEMENTED INTERVENTIONS

16.1 INTRODUCTION

This chapter provides information on evaluating the estimated safety effect of certain highway improvements and the overall affect diverse improvements can have on the entire safety improvement program. The safety evaluation process is the final step within a safety improvement program. Estimating the true safety affects is an important ongoing effort, yet it is a complicated task. If the evaluation is to be done correctly, unique expertise in appropriate estimation procedures is needed. For this reason, RPDOM professionals should not be encouraged to engage in the estimation of safety effects because to do so requires expertise they seldom posses. However, they should be able to critically assess published results, to understand what data is needed to account for the most important factors, and how much of it is needed to attain a specified precision. The focus of this chapter is to stress the importance of evaluating the estimated safety effects of improvements and guides the professional on how to properly have the evaluation done.

Note: Special Requirements

The evaluation of estimated safety effects is a complex process. To properly conduct an evaluation, a skilled professional with unique expertise is required. Therefore, the RPDOM professional should seek the services of those uniquely qualified to conduct the evaluation.

16.2 WHY EVALUATE?

This section should discuss what an evaluation is and the importance of conducting an evaluation based on sound statistical methods. The author should consult, "The Accident Research Manual: An Abridged Version (June 1997)" and the "Highway Safety Evaluation Procedural Guide (Nov. 1981)", FHWA-TS-81-219.

16.3 DATA NEEDS AND LIMITATIONS

There are many peculiarities of highway safety data requiring special analytical methods to accommodate them. These include poor quality of accident and traffic volume data and accident reporting differences among jurisdictions. The need to maintain quality accident data by improving the data collection process is apparent. Unfortunately, only a few jurisdictions have in place a system that easily link accident, traffic and inventory data into a database that could facilitate the most advanced methods of highway safety analysis. The author should consult "NCHRP Synthesis 295 -Statistical Methods in Highway Safety" Analysis to discuss data needs and limitations.

16.4 APPROACH TO CONDUCTING A VALID EVALUATION

The author should refer to "Observational Before-After Studies In Road Safety" (1997), Ezra Hauer to describe the best approach to this topic.

Before-After studies

- Major study types and threats to their validity
- Accounting for change and for selection bias
- Data needs and study design
- Effect estimation and its precision in simple cases

Multivariate statistical modeling

- Types of models and threats to validity
- Model form, choice of variables, error structure
- Data needs

GLOSSARY

This section will contain a glossary of terms and acronyms that are used in the manual but may not be familiar to all users. Examples include the terms accident modification factor, base model, and algorithm.

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APPENDIX B: WORK PLAN FOR COMPLETING THE FIRST EDITION OF THE HIGHWAY SAFETY MANUAL

INTRODUCTION

The purpose of the Highway Safety Manual (HSM) will be to provide the best factual information and tools, in a useful and widely accepted form, to facilitate roadway design and operational decisions based upon explicit consideration of their safety consequences. This document presents a strategic work plan for completing the first edition of the HSM.

Scope of Work Plan

The scope of this strategic work plan is the creation of a first edition of the HSM. This work plan does not detail the steps necessary to create an ultimate edition of the HSM. However, the work plan is drafted in the context that there will be subsequent editions after the first edition. As such, there are some elements included in this work plan that are intended to facilitate the creation of future editions.

Overview

The work plan for the first edition of the Highway Safety Manual (HSM) consists of four elements: an action plan, a level of effort estimate for each of the proposed chapters, a schedule of activities, and an identification of research needs.

The work plan assumes that the present HSM Joint Subcommittee (JSC) will be recognized by TRB first as an HSM Task Force and ultimately as a Standing Committee. It includes activities of the HSM Task Force , an NCHRP panel, TRB, FHWA, and contractors. The work plan includes the services of a contractor that will be the coordinator of the production of a final draft of the HSM. This contractor would be responsible for coordinating the production of all of the chapters to ensure that they are consistent.

The work plan includes a test group review of each of the parts of draft HSM. HSM Task Force members would be leading candidates for participation in this testing. The HSM Task Force would identify additional testing reviewers from interested state and local agencies.

This work plan does not explicitly address the development of software to implement the HSM procedures. The reason for this omission is the TRB, the intended owner of the HSM, has chosen not to produce software for the Highway Capacity Manual (HCM), and will presumably make that same choice with respect to the HSM. Software for the two-lane rural highway safety estimation procedures in the HSM prototype chapter has been developed by FHWA for use in the Interactive Highway Safety Design Model (IHSDM). It is suggested that the HSM Task Force contact FHWA to determine their potential interest in developing IHSDM software for the other HSM methodologies. This could result in IHSDM becoming the software implementation for the HSM procedures.

Time Span

The intention of the Joint Subcommittee in the year 2000 was to produce a first edition of the HSM in five years. This work plan details the creation and delivery of a first edition of the HSM in December 2007, approximately 2 years later than originally intended. This publication date is based on what is hoped to be a realistic assessment of the likely funding cycle for impact research.

ACTION PLAN

The action plan identifies and briefly describes the tasks and subtasks necessary to create the first edition. The action plan specifies three types of tasks, categorized by their overall function: preparation tasks, development tasks, and composition and production tasks. The tasks are not listed chronologically. For the order of the tasks, please refer to the schedule section. Each of the tasks and subtasks are documented in tables in the following sections.

Preparation Tasks

Preparation tasks are those tasks that will establish the structure of the HSM and the structure of the process for developing the HSM. They are presented in Table B-1. Many of these tasks, although classified as preparation tasks, are more suitably referred to as coordination tasks. These tasks will continue throughout the development of the first edition of the HSM. These tasks are important not only for the development of the first edition of the HSM but also for the development of subsequent editions of the HSM. The costs, duration of effort, and start and end dates are all estimated by the contractor.

Table B-1. Preparation Tasks

PREPARATION TASKS						
ITEM	DESCRIPTION	COMMENT	RESPONSIBILITY	ESTIMATED COSTS	DURATION OF EFFORT	START DATE
P-1	TRB recognize HSM joint subcommittee first as a Task Force and then as a full-fledged Standing Committee	In process	TRB	---	--- 3 years with a task force status, indefinite beyond	On-going
P-2	Identify and define roles and functions of the Task Force	Not yet fully established, although there has been discussion among the participants	HSM Task Force	---	1 year, although it could take longer	On-going
P-3	Seek user input on needs for the first edition HSM and subsequent editions	Ensure solicitation, receipt, and consideration of inputs from all user groups, resulting in a system of checks and balances. The User Liaison task group will be responsible for this activity	HSM Task Force	---	On-going	January 2003 to indefinite

PREPARATION TASKS						
ITEM	DESCRIPTION	COMMENT	RESPONSIBILITY	ESTIMATED COSTS	DURATION OF EFFORT	START DATE
P-4	Oversee programming and prioritization of subsequent research activity	Plan a coherent research program. Make funding agencies aware of research needs. Monitor progress and adapt plans as needed. The Implementation task group will be responsible for this activity.	HSM Task Force	---	On-going	January 2003 to indefinite
P-5	Identify test groups for review of fundamentals chapters (Part I)	Identify candidate state and local agencies to supplement the HSM Task Force. Either the Content or User Liaison task group would have responsibility for this work.	HSM Task Force	---	6 months	January 2005 – June 2005
P-6	Identify test groups for review of knowledge chapters (Part II)	Identify candidate state and local agencies to supplement the HSM Task Force. Either the Content or User Liaison task group would have responsibility for this work.	HSM Task Force	---	6 months	January 2005 – June 2005

PREPARATION TASKS						
ITEM	DESCRIPTION	COMMENT	RESPONSIBILITY	ESTIMATED COSTS	DURATION OF EFFORT	START DATE
P-7	Identify test groups for pilot testing of applications chapters (Part III)	Identify candidate state and local agencies to supplement the HSM Task Force; there will likely be separate test groups for each of the chapters in Part III. Either the Content or User Liaison task group would have responsibility for this work.	HSM Task Force	---	6 months	January 2004 – June 2004 for two-lane chapter; January 2005 - June 2005 for other chapters
P-8	Identify test groups for pilot testing of safety management chapters (Part IV)	Identify candidate state and local agencies to supplement the HSM Task Force. Either the Content or User Liaison task group would have responsibility for this work.	HSM Task Force	---	6 months	January 2005 – June 2005
P-9	Identify test groups for pilot testing of safety evaluation chapter (Part V)	Identify candidate state and local agencies to supplement the HSM Task Force. Either the Content or User Liaison task group would have responsibility for this work.	HSM Task Force	---	6 months	January 2005 – June 2005

PREPARATION TASKS						
ITEM	DESCRIPTION	COMMENT	RESPONSIBILITY	ESTIMATED COSTS	DURATION OF EFFORT	START DATE
P-10	Establish protocols for future research efforts and criteria for inclusion of materials in the HSM	Due to the need to continue with the development work, this activity needs to be completed soon. This effort would also extend to encompass the peer review process of materials and subsequent development of future editions of the HSM. The Content and Research Protocols task groups would have responsibility for this work.	HSM Task Force	---	18 months	September 2002 to December 2003
P-11	Identify and implement process to review materials for the HSM	Establishment of the review process is the responsibility of the Content task group.	HSM Task Force	---	1 year	January 2003 - December 2003
P-12	Establish and maintain liaisons with other organizations and initiatives, such as AASHTO, FSHRP, R&T, etc.	Inform interested organizations about plans for HSM and seek input.	HSM Task Force	---	Ongoing	January 2003 to indefinite

PREPARATION TASKS						
ITEM	DESCRIPTION	COMMENT	RESPONSIBILITY	ESTIMATED COSTS	DURATION OF EFFORT	START DATE
P-13	Identify specifications for the format of the HSM	The prototype chapter developed under NCHRP 17-18(4) presents a potential format; finalization of format specifications accomplished by a subcommittee of the full HSM committee	HSM Task Force	---	6 months	January – June 2003

PREPARATION TASKS						
ITEM	DESCRIPTION	COMMENT	RESPONSIBILITY	ESTIMATED COSTS	DURATION OF EFFORT	START DATE
P-14 14a 14b 14c 14d 14e 14f 14g 14h	Coordinate efforts to produce the first edition HSM Coordinate preliminary activities prior to the selection of a contractor. Encourage funding agencies to provide funds for this work. Monitor production activities. Develop HSM marketing plan. Provide status reports to the full HSM Task Force. Ensure that all HSM materials are reviewed by the full HSM Task Force. Assure that approved HSM materials are provided to TRB for publication. Finalize plans for future HSM editions.	Item P-14 includes the activities of the HSM Task Force in overseeing the production of the HSM. Initially, all activities would be conducted internally by the HSM Task Force. After the contract work anticipated in Item C-16 begins, the HSM Task Force would review materials generated by the contractor. When approved by the full HSM committee, materials would be delivered to TRB for publication as part of Item C-8. The Content task group would be responsible for these activities.	HSM Task Force	---	54 months	June 2003 – completion of first edition HSM

Development Tasks

Development tasks consist of those tasks necessary to develop the material that will constitute the HSM. They are presented in Table B-2. These tasks include activities such as conducting research and developing accident prediction models. Development tasks will be identified for various roadway types and will likely be conducted concurrently.

Table B-2. Development Tasks

DEVELOPMENT TASKS						
ITEM	DESCRIPTION	COMMENT	RESPONSIBILITY	ESTIMATED COSTS	DURATION OF EFFORT	START AND END DATE
D-1	Conduct basic research on rural, two-lane roads to develop accident prediction models/methodology	Completed (results included in prototype chapter)	Funded Research	N/A	N/A	Completed March 2003
D-2	Develop application tool for accident prediction model for rural, two-lane roads	Completed (results included in prototype chapter)	Funded Research	N/A	N/A	
D-3	Continue basic research on rural, two-lane roads and revise accident prediction models/methodology, if found by the HSM Task Force to be needed following review of the materials developed in D-1 and D-2.	HSM Task Force will seek funded research if a need is identified. This work will be conducted jointly with Item C-2.	Funded Research	$200,000 (optional; may not be needed if HSM Task Force accepts prototype chapter; funding level may vary based on results of HSM Task Force review)	1 year	March 2005 - February 2006

DEVELOPMENT TASKS						
ITEM	DESCRIPTION	COMMENT	RESPONSIBILITY	ESTIMATED COSTS	DURATION OF EFFORT	START AND END DATE
D-4	Conduct basic research on multilane rural roads to develop accident prediction models/methodology	Preliminary research by FHWA is underway. Contractor for Item D-4 should utilize the FHWA results and conduct further research to develop a complete accident prediction methodology. A research problem statement for Items D-4 and D-5 has been developed by the HSM Task Force.	Funded Research	$500,000*	24 months for Items D-4 and D-5 combined	March 2004 - February 2006
D-5	Develop application tool for accident prediction model for multilane rural roadways	Same contractor as for Item D-4 would complete this task. This work is included in the research problem statement already developed by the HSM Task Force.	Funded Research	Included in budget for Item D-4	24 months for Items D-4 and D-5 combined	March 2004 - February 2006

* Supplementary funding of $250,000 is included in Item C-3

DEVELOPMENT TASKS						
ITEM	DESCRIPTION	COMMENT	RESPONSIBILITY	ESTIMATED COSTS	DURATION OF EFFORT	START AND END DATE
D-6	Conduct basic research on urban and suburban arterials to develop accident prediction models/methodology	The work in Items D-6 and D-7 has been funded as NCHRP Project 17-26.	Funded Research	$500,000*	24 months for Items D-6 and D-7 combined	March 2003 – February 2005
D-7	Develop application tool for accident prediction model for urban and suburban arterials	Same contractor as for Item D-6 would complete this task	Funded Research	Included in Task D-6 budget	24 months for Items D-6 and D-7 combined	March 2003 – February 2005
D-8	Develop test scenarios to evaluate models for reasonableness (includes testing of models, methodologies, and tools developed in Items D-1 through D-7)	Developed by the HSM committee members, especially the user liaison group; test scenarios used for review and acceptance testing of models	HSM Task Force	---	Ongoing	June 2004 – indefinite

* Supplementary funding of $250,000 is included in Item C-4

Development tasks for future editions would include similar tasks as those outlined above for other roadway types and geometric situations. These tasks will likely include the basic research and application tool development for the following roadway types and geometric situations:

- Urban collectors,
- Interchanges,
- Railroad/highway grade crossings,
- Arterial weaving areas,
- Multi-modal facilities,
- Freeways, and
- Local streets.

In addition to the roadway types and geometric situations that will require development tasks for future editions, there are also some emerging issues that will require development work so that they can be addressed in subsequent editions of the HSM. These are topics that will be identified by the user liaison subcommittee as having particular relevance for the RPDOM audience. Examples of the types of topics that may be identified as emerging issues include:

- Pedestrian measures,
- Alterations in the number of lanes of a roadway without additions in ROW,
- Measures for older drivers,
- Red light photo enforcement cameras, and
- Parking management.

Composition and Production Tasks

Composition and production tasks consist of those tasks necessary to produce the content of the HSM. They are presented Table B-3. It is assumed that the contractor(s) responsible for the development of the application tools for Chapter 9 and Chapter 10 of Part III will also be responsible for producing the associated chapters. Therefore, there are no subtasks to identify a contractor for these tasks.

Table B-3. Composition and Production Tasks

COMPOSITION AND PRODUCTION TASKS						
ITEM	DESCRIPTION	COMMENT	RESPONSIBILITY	ESTIMATED COSTS	DURATION OF EFFORT	START AND END DATE
C-1	Write HSM Parts I and II	Draft outline established; A research problem statement for this effort has been developed by the HSM Task Force.	Funded Research	$200,000	18 Months	March 2004 – August 2005
C-2 2a 2b	Complete research and write Part III, Chapter 8: Rural, Two-Lane Roads Develop chapter 8 prototype material Committee review and revise	Prototype chapter developed under NCHRP 17-18(4) contract. Currently undergoing review. Further research and revision of this material will be conducted in Item D-3, if needed.	Funded Research	See estimated cost for Item D-3	1 year	March 2005 – February 2006

COMPOSITION AND PRODUCTION TASKS						
ITEM	DESCRIPTION	COMMENT	RESPONSIBILITY	ESTIMATED COSTS	DURATION OF EFFORT	START AND END DATE
C-3	Complete research and write Part III, Chapter 9: Rural, Multilane Highways	Draft outline established. Contractor identified in Items D-4 and D-5 would be responsible for performing research and revising chapter.	Funded Research	$250,000	12 months	March 2006 – February 2007
3a	Draft content of chapter 9. (Based on Items D-4 and D-5.)					
3b	Committee review					
3c	Consider user needs and format issues					
3d	Develop revised chapter 9					
3e	Issue drafts to selected test groups (identified in Items P-7) for review					
3f	Perform further research as needed based on HSM Task Force review and testing					
3g	Finalize chapter 9 content					

COMPOSITION AND PRODUCTION TASKS						
ITEM	DESCRIPTION	COMMENT	RESPONSIBILITY	ESTIMATED COSTS	DURATION OF EFFORT	START AND END DATE
C-4 4a 4b 4c 4d 4e 4f 4g	Complete research and write Part III, Chapter 10: Urban and Suburban Arterials Draft content of chapter 10. (Based on Items D-6 and D-7.) Committee review Consider user needs and format issues Develop revised chapter 10 Issue drafts to selected test groups (identified in Item P-7) for review Perform further research as needed based on HSM Task Force reviews and testing. Finalize chapter 10 content	Draft outline established. Contractor identified in Items D-6 and D-7 would be responsible for performing research and revising chapter.	Funded Research	$250,000	12 months	March 2005 – February 2006
C-5	Write HSM Part IV and V	Draft outline established, extent of content yet to be determined	Funded Research	$200,000	12 months	March 2005 – February 2006

COMPOSITION AND PRODUCTION TASKS						
ITEM	DESCRIPTION	COMMENT	RESPONSIBILITY	ESTIMATED COSTS	DURATION OF EFFORT	START AND END DATE
C-6 6a 6b 6c 6d 6e 6f 6g 6h	Produce final draft HSM Conduct synthesis effort involving multimedia education expertise. Identify delivery media for HSM and obtain approval of TRB and the HSM Task Force. Implement marketing plan developed in Item P-15. Combine products of Items C-1 through C-5 into draft HSM Edit drafts for technical consistency and convert to format developed in Item P-13. Submit draft for review to NCHRP panel and TRB full committee Ensure HSM has 508 compliant descriptions of all material. Revise draft in response to NCHRP panel and HSM Task Force comments. Submit final draft for publication by TRB on approved delivery media in Item C-8.	A contractor will be needed to facilitate production of the HSM.	Funded Research	$600,000	24 months	March 2005 – June 2007

COMPOSITION AND PRODUCTION TASKS						
ITEM	DESCRIPTION	COMMENT	RESPONSIBILITY	ESTIMATED COSTS	DURATION OF EFFORT	START AND END DATE
C-7	Develop HSM training materials	Develop training materials for use in implementing the HSM, particularly the chapters with quantitative procedures.	Funded Research	$200,000	12 months	January – December 2007
C-8 8a 8b 8c 8d	Publish HSM on delivery media identified in Item C-6 and approved by the HSM Task Force and TRB. Translate final draft into media Program 508 complaint material into media Beta-test HSM Release first edition of HSM	Details of this task are highly variable depending on the delivery media selected in Item C-6.	TRB	Depends on media selected in Task P-5.	3 months	July – December 2007

LEVEL OF EFFORT ESTIMATES

The level of effort in man hours expended, approximate labor costs assuming $125/person-hour, and pages produced was estimated for each of the proposed chapters in the draft of the first edition of the HSM. The chapters for Part I, II, III, and V are presented in Table B-4. The chapters for Part IV are presented in a Table B-5 because the extent of the content has not been determined. Therefore, estimates are presented for two different scenarios.

Table B-4. Level of Effort Estimates for Parts I, II, III, and V of the First Edition Highway Safety Manual

Section	Estimated Level of Effort (hours)		Estimated Labor Costs ($)		Page Estimate	
	Low[!]	High[++]	Low	High	Low	High
Part I – Introduction and Fundamentals						
Chapter 1. Introduction and Overview	40	80	$5,000	$10,000	10	
Chapter 2. Fundamentals	160	320	$20,000	$40,000	30	40
Part II – Knowledge						
Chapter 3. Roadway Segments	320	480	$40,000	$60,000	100	
Chapter 4. Intersections	280	480	$35,000	$60,000	75	125
Chapter 5: Interchanges	160	320	$20,000	$40,000	50	
Chapter 6: Special Facilities and Geometric Situations	120	160	$15,000	$20,000	25	40
Chapter 7. Road Network	120	160	$15,000	$20,000	25	30
Part III – Predictive Methods						
Chapter 8. Rural, Two-Lane Roads	Preliminary Draft prepared under 17-18 (4) contract				90	
Chapter 9. Rural, Multilane Highways	480[*]	600[*]			110[*]	
Chapter 10. Urban and Suburban Arterial Highways	2,400	5,000			130	
Part V – Safety Evaluation						
Chapter 16. Overview of Estimating the Safety Effect of Implemented Interventions	120	200	$15,000	$25,000	20	

[!] Assumed effort for production of first “cut”.
[++] Includes time for author to meet, discuss/debate and then revise.
[*] Exclusive of effort being covered under separate contracts.

Because the extent of the content for Part IV has not been determined, two estimates are provided for both the level of effort and the pages. The estimates presented in the second and third column are for Scenario 1. Scenario 1 assumes that the material will be fully developed in the first edition of the HSM. The estimates presented in the last two columns, Scenario 2, assume that the material will not be fully developed in the first edition but instead will provide overview information and direct the reader to other resources.

Table B-5. Level of Effort Estimates for Part IV of the First Edition Highway Safety Manual

Part IV – Safety Management of a Roadway System	Scenario 1: Full Development			Scenario 2: Overview		
	Person Hours	Labor Cost	Pages	Person Hours	Labor Cost	Pages
Chapter 11. Identification of Sites with Promise	200-400	$25,000-$50,000	40	80	$10,000	10
Chapter 12. Diagnosis of the Nature of Safety Problems at Specific Sites	200-400	$25,000-$50,000	50	120	$15,000	15
Chapter 13. Selection of Countermeasures to Reduce Accident Frequency and Severity at Specific Sites	200-400	$25,000-$50,000	40	120	$15,000	15
Chapter 14. Economic Appraisal of all Sites under Consideration	200-360	$25,000-$45,000	40	80	$10,000	10
Chapter 15. Prioritize Rankings of Improvement Projects	200-320	$25,000-$40,000	30	80	$10,000	10

Table B-6 presents totals of the estimates for all sixteen of the proposed first edition chapters. Totals are provided for both Scenario 1 and Scenario 2.

Table B-6. Level of Effort Estimates for All Parts of the First Edition Highway Safety Manual

Total	Level of Effort (in hours)		Page Estimate	
	Low[!]	High[++]	Low	High
Scenario 1	6,280	10,880	865	945
Scenario 2	5,680	10,160	725	805

[!] Assumed effort for production of first "cut".

[++] Includes time for author to meet, discuss/debate and then revise.

The estimated cost of the entire first edition of the HSM is approximately $3.1 million, of which $0.7 million has already been funded. Some of these costs such as chapter composition can be directly attributed to individual chapters. Other costs such as Task C-6, produce final draft HSM, are attributed to the entire manual. Those costs that can be attributed to individual chapters are presented by chapter in Table B-7. A schedule of activities is presented in Table B-8.

Table B-7. Estimated Costs of Individual Chapters of the First Edition Highway Safety Manual

Section	Costs Directly Attributed to Chapter
PART I – INTRODUCTION AND FUNDAMENTALS	$200,000
Chapter 1. Introduction and Overview	
Chapter 2. Fundamentals	
PART II – KNOWLEDGE	
Chapter 3. Highway Segments	
Chapter 4. Intersections	
Chapter 5: Interchanges	
Chapter 6: Special Facilities and Geometric Situations	
Chapter 7. Road Network Considerations	
PART III – PREDICTIVE METHODS	
Chapter 8. Rural, Two-Lane Roads	$200,000*
Chapter 9. Rural, Multilane Highways	$750,000
Chapter 10. Urban and Suburban Arterial Highways	$750,000
PART IV – SAFETY MANAGEMENT OF A ROADWAY SYSTEM	$200,000
Chapter 11. Identification of Sites With Promise	
Chapter 12. Diagnosis of the Nature of Safety Problems at Specific Sites	
Chapter 13. Selection of Countermeasures to Reduce Accident Frequency and Severity at Specific Sites	
Chapter 14. Economic Appraisal of All Sites Under Consideration	
Chapter 15. Prioritize Rankings of Improvement Projects	
PART V – SAFETY EVALUATION	
Chapter 16. Overview of Estimating the Safety Effect of Implemented Interventions	

* in addition to funds already expended by FHWA and in NCHRP Project 17-18(4)

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Table B-8. Schedule of Activities

		Task	2003	2004	2005	2006	2007
			J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
Preparation	P-1	TRB recognize Task Force, Committee	-----On-going ------------------------On-going	---------------------On-going -------------------	---On-going -------------------- On-going--	-----------------On-going ------------------	On-going ------------------------ --On-
	P-2	Identify/define Task Force roles,functions	----------------------On-going ------------------	---- On-going--------------------------On-going	------------------------On-going ----------------	-- On-going----------------------On-going -	---------------On-going------------------
	P-3	Seek user input on needs for HSM	---On-going --------------------- On-going--	---------------------On-going ---------------	-On-going ----------------------- On-going---	----------------On-going ----------------On-going	-going ------------------------------On-
	P-4	Oversee prog. & priority of research	----------------------On-going ------------------	---- On-going--------------------------On-going	------------------------On-going ----------------	-- On-going----------------------On-going -	---------------On-going ------------------
	P-5	Identify test groups for Part I					
	P-6	Identify test groups for Part II					
	P-7	Identify test groups for Part III					
	P-8	Identify test groups for Part IV					
	P-9	Identify test groups for Part V					
	P-10	Establish research protocols & criteria					
	P-11	Identify & implement review process					
	P-12	Establish & maintain liaisons w/others					
	P-13	Identify specifications for HSM format					
	P-14	Coordinate first edition production					
Development	D-1	Rural, two-lane roads research					
	D-2	Develop rural, two-lane tool	-------First draft produced------				
	D-3	Cont.research & revise rural two-lane tool					
	D-4	Multilane rural roads research					
	D-5	Develop multilane rural roads tool					
	D-6	Urban and suburban arterials research					
	D-7	Develop urban and suburban arterials tool					
	D-8	Develop test scenarios					
Composition/Production	C-1	Write HSM Parts I and II					
	C-2	Produce Part III, Chapter 8	-----Prototype produced ----				
	C-3	Produce Part III, Chapter 9					
	C-4	Produce Part III, Chapter 10					
	C-5	Write Parts IV and V					
	C-6	Produce final draft HSM					
	C-7	Develop HSM training materials					
	C-8	Publish HSM on delivery media					

RESEARCH NEEDS

Immediate Research Needs

The immediate research efforts that are needed to produce the first edition of the HSM are documented below.

- **Urban and Suburban Arterials.** NCHRP Project 17-26 will develop models for prediction of the expected safety performance of urban and suburban arterials.
- **Rural Multilane Highways.** In the context of the on-going work in other roadway types (e.g., urban and suburban arterials), rural multilane highways are the next logical roadway type to begin development. Currently, there are several, separate ongoing research efforts addressing a portion of the needs for modeling the safety performance of this roadway class. A research project is needed to coordinate the findings of the current research efforts, identify and address any gaps in the research, develop the rural multilane highway model, develop the analytical tool, and write the corresponding analytical chapter for Part III of the HSM.
- **Identify Gaps/Deficiencies in Two-Lane Rural Predictive Tool.** A tool for predicting the expected accidents on rural, two-lane roadways has been developed and is the basis of the prototype chapter developed for Part III. However, there have been advances in research since the original development of the tool and the HSM Task Force review of the prototype chapter may lead to a need for further research.
- **Write HSM Parts I and II.** A research effort would be needed to write HSM Part I (Introduction and Overview) and Part II (Knowledge).
- **Write HSM Parts IV and V.** A research effort would be needed to write HSM Part IV (Safety Management of a Roadway System) and Part V (Safety Evaluation).
- **Produce Final HSM Draft.** A research effort would be needed to produce the final HSM draft. This would pull together drafts prepared in previous contracts into a consistent document that meets the format guidelines established by the HSM Task Force. This contract would also include a synthesis effort involving multimedia education expertise, identification of the delivery media for the HSM, and implementation of the HSM marketing plan. The final HSM draft, after approval by the HSM Task Force, would be delivered to TRB for publication.
- **HSM Training Course Development.** A research effort would be needed to develop a user-oriented training course on application of the HSM in practical decision making.

Table B-9 presents the estimated research funding needed for the First Edition HSM. Table B-10 presents the estimated schedule for research.

Table B-9. Funded Research Needs for First Edition HSM

Planning/Scoping Study	$200,000*
Parts I and II (Items C-1 through C-7)	$200,000
Part III (Rural Two-Lane Roads) (Items D-3 and C-8)	$200,000
Part III (Rural Multilane Roads) (Items D-4, D-5, and C-9)	$750,000
Part III (Urban and Suburban Arterials) (Items D-6, D-7, and C-10)	$750,000**
Parts IV and V (Items (C-11 and C-12)	$200,000
HSM Production (Items P-4, P-11, P-15, C-13, and C-14)	600,000
HSM Training Course Development	$200,000
TOTAL	$3,100,000

* $200,000 has already been allocated for this effort in NCHRP Project 17-18(4) and this work is nearly complete.

** $500,000 has already been allocated for Items D-6 and D-7 in NCHRP Project 17-26.

Table B-10. Time Schedule for Funded Research

Planning/Scoping Study	January 2001 – March 2003
Parts I and II	March 2004 – August 2005
Part III (Rural Two-Lane Roads)	March 2005 – February 2006
Part III (Rural Multilane Roads) Initial Contract Further Research/Revisions	 March 2004 – February 2006 March 2006 – February 2007
Part III (Urban and Suburban Arterials) Initial Contract Further Research/Revisions	 March 2003 – February 2005 March 2005 – February 2006
Parts IV and V	March 2005 – February 2006
HSM Production	March 2005 – June 2007
HSM Training Course Development	January 2007 – December 2007
TRB Publication process	July 2007 – December 2007

NOTE: Beginning in December 2004 and continuing through early 2007, the JSC will be receiving draft chapters to review. Each chapter will be reviewed four times (research contractor draft, research contractor final, production contractor draft, production contractor final) and some will be reviewed additional times. It needs to be worked out whether the JSC, as well as the project panel, will participate in all of these reviews. Some of these reviews will need to be turned around quickly to meet contract schedules.

CONCLUSION

This work plan presents actions needed to develop the first edition of the Highway Safety Manual. Although this work plan does not outline the actions necessary to develop an ultimate edition of the HSM, it is presented in the context that there will be subsequent editions of the HSM. The work plan presented here is intended not just to produce the first edition but also facilitate the production of subsequent editions.

HIGHWAY SAFETY MANUAL

PROTOTYPE CHAPTER

Two-Lane Highways

NCHRP Project 17-18(4)

Bellomo-McGee Inc.
Vienna, Virginia

Midwest Research Institute
Kansas City, Missouri

February 2003

Prototype Chapter

TWO-LANE HIGHWAY

CONTENTS

EXHIBITS

I. INTRODUCTION

This chapter presents a comprehensive procedure for predicting the safety performance of two-lane highways. The development of the procedure combined the use of historical accident data, regression analyses, before-and-after studies, and expert judgment to make better safety predictions than those that could be made by any of these approaches alone. The development of the procedure is documented by Harwood et al. *(1)*.

SCOPE OF THE METHODOLOGY

The safety analysis methodology presented in this chapter estimates the safety performance for an existing or proposed rural two-lane highway operating under current or projected traffic demand. The safety performance measure for two-lane highways is the expected annual accident frequency, which can be calculated for a particular roadway segment, intersection, or entire project.

The recommended approach to accident prediction has its basis in published safety literature, including both before-and-after evaluations and regression models. It is sensitive to the geometric features that are of greatest interest to highway designers and incorporates judgments made by a broadly based group of safety experts. The two-lane highway methodology addresses all types of rural two-lane highway facilities, including two-lane highways with added passing lanes and two-lane highways containing short sections of four-lane highway to increase passing opportunities (i.e., side-by-side passing lanes).

LIMITATIONS OF THE METHODOLOGY

The major limitation of the methodology is that it incorporates the effects on safety of many, but not all, geometric and traffic control features of potential interest. Only those geometric features whose relationship to safety is well understood are included in the procedure. Furthermore, the model generally treats the effects of individual geometric design and traffic control features as independent of one another and ignores potential interactions between them. It is likely that such interactions exist, and ideally, they should be accounted for in the safety prediction procedure; however, such interactions are poorly understood and difficult to quantify.

II. METHODOLOGY

This section provides an overview of the safety prediction methodology for rural two-lane highways. The methodology includes safety prediction procedures for roadway segments and intersections together with a method for combining the results of the two procedures to obtain a prediction of the safety performance for an entire two-lane highway facility.

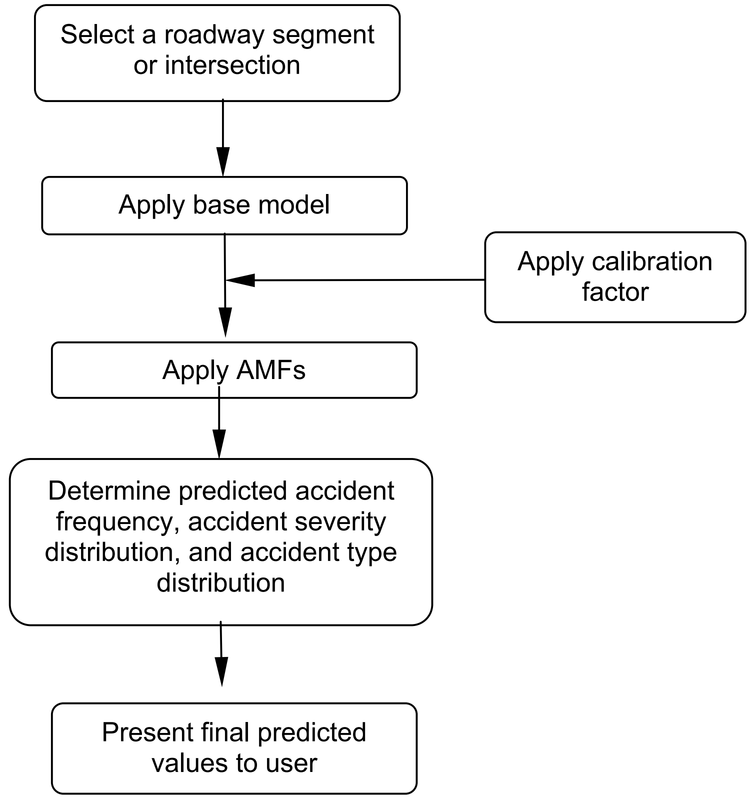
OVERVIEW OF SAFETY PREDICTION METHODOLOGY

Separate safety prediction procedures have been developed for roadway segments and for three types of at-grade intersections. These separate procedures can be used together to predict the total accident frequency for an entire two-lane highway section or improvement project.

Exhibit 1 presents the overall structure of the two-lane highway safety prediction procedures for roadway segments or for intersections. The basic components of the procedure include base models, accident modification factors (AMFs), and calibration factors. These elements of the safety prediction methodology are presented below.

Structure of safety prediction methodology.

EXHIBIT 1. TWO-LANE HIGHWAY SAFETY PREDICTION METHODOLOGY



Structure of the Safety Prediction Procedures

The safety prediction procedures for roadway segments and at-grade intersections are each composed of two components: base models and accident modification factors. A calibration factor can be used to adapt the procedure to local conditions. These components and the manner in which they are combined, are presented in this section.

Base Models

Base models are used to predict safety for nominal or base conditions.

The base model used in each safety prediction procedure is a regression model for predicting the total accident frequency of each roadway segment or intersection on a two-lane highway. The base model, like all regression models, predicts the value of a dependent variable as a function of a set of independent variables. In each safety prediction procedure, the dependent variable estimated in the base model is the annual accident frequency for a roadway segment or intersection and the independent variables are traffic volumes and geometric design or traffic control features of that roadway segment or intersection.

Regression models like the base models are useful in predicting overall accident frequency, but their coefficients cannot necessarily be relied upon to represent the incremental effects of individual geometric design and traffic control features; therefore, the base models are not sufficient, by themselves, to make reliable predictions of safety performance of a two-lane highway segment or intersection because they are not necessarily sensitive to all of the geometric design and traffic control features of interest. The base models are used only to estimate the expected accident frequency for a specified set of nominal base conditions, such as 12-ft lane widths and 6-ft shoulder widths. This base estimate of accident frequency is then adjusted with AMFs that represent the safety effects of individual geometric design and traffic control elements.

Accident Modification Factors

The AMFs are multiplicative factors used to adjust the base accident frequency for the effect of individual geometric design and traffic control features. The AMF for the nominal or base value of each geometric design traffic control feature has a value of 1.0. Any feature associated with higher accident experience than the nominal or base condition has an AMF with a value greater than 1.0; any feature associated with lower accident experience than the base condition has an AMF with a value less than 1.0.

The AMFs in the safety prediction procedure were determined from a comprehensive literature review by an expert panel. They represent the collective judgment of the expert panel concerning the safety effects of each geometric design and traffic control feature of interest.

Calibration of the Methodology to Local Conditions

The safety prediction methodology is intended for use throughout the United States. Accident frequencies, even for nominally similar roadway sections or intersections, are known to vary widely from state to state. These variations are of two types, those that can be directly accounted for by the safety prediction procedure and those that cannot.

States differ markedly in climate, animal population, driver populations, accident reporting threshold, and accident reporting practices. These variations may result in some states experiencing substantially more reported traffic accidents on rural two-lane highways than others; in some states there may be substantial variations in safety conditions between areas of the state. Calibration factors are included in the methodology to allow highway agencies to adjust the safety prediction procedure to match actual local safety conditions.

The calibration procedure is implemented by determining the value of calibration factors for roadway segments and at-grade intersections from comparison of existing statewide data to estimates from the safety prediction methodology.

Calibration procedures are presented in Appendix A.

The calibration factors (defined below as C_r and C_i) will have values greater than 1.0 for roadways that, on the average, experience more accidents than the roadways used in the development of the base models. The calibration factors for roadways that, on the average, experience fewer accidents than the roadways used in the development of the base models will have values less than 1.0. The calibration procedures are presented in Appendix A.

In addition to estimates of accident frequency, the safety prediction procedure includes default distributions of accident severity and accident type for two-lane highway roadway sections and intersections. These default distributions are presented in Exhibits 2 and 3. The calibration procedure presented in Appendix A describes how the safety prediction methodology can be used to modify the default distributions of accident severity and accident type to match a specific experience on two-lane highways.

Subdividing a Two-Lane Highway Facility

To apply the methodology, the facility must be sub-divided into individual homo-geneous roadway segments and intersections. A new segment starts where any of the variables listed here changes.

Before the safety prediction methodology can be applied to an existing or proposed two-lane highway facility, the roadway must be divided into analysis unit consisting of individual homogeneous roadway segments and intersections. A new roadway segment begins at each location where the value of one of the following variables changes:

- Average daily traffic volume (veh/day)
- Lane width
- Shoulder width
- Shoulder type
- Driveway density (driveways per mile)
- Roadside hazard rating

Also, a new roadway segment starts at any of the following locations:

- Intersection
- Beginning or end of a horizontal curve

- Point of vertical intersection (PVI) for a crest vertical curve, a sag vertical curve, or an angle point at which two different roadway grades meet
- Beginning or end of a passing lane or short four-lane section provided for the purpose of increasing passing opportunities
- Beginning or end of a center two-way left-turn lane

In addition, each individual at-grade intersection on the two-lane highway facility is treated as a separate analysis unit.

New highway segments begin at points 250 feet before and after the center of each intersection and at the center of each intersection. If the centers are less than 500 feet apart, a new highway segment begins at the midpoint between the two centers of the intersections. After this segmentation process, the roadway to be evaluated will consist of roadway segments of varying length, each of which is homogenous with respect to traffic volume, lane width, shoulder width, shoulder type, driveway density, roadside hazard rating, curvature, grade, presence of passing lanes or short four-lane sections, and presence of center two-way left turn lanes. It should be noted that for purposes of this chapter spiral transitions are considered part of the horizontal curve they adjoin and vertical curves are considered part of the grades they adjoin (i.e., grades run from PVI to PVI with no explicit consideration of any vertical curve that may be present).

Roadway Segments

The safety prediction procedure for roadway segments estimates the expected total annual *nonintersection-related* accidents frequency for each of the segments that make up a highway project. Nonintersection-related accidents include accidents that occur near an intersection, but are not related to the intersection, and accidents that occur on roadway segments between intersections. The general formula for predicting the safety performance of a roadway segment, combining the base models, AMFs, and calibration factor, is presented below:

Accident frequencies for roadway segments are predicted with Equation (1).

$$N_{rs} = N_{br}\, C_r\, (AMF_{1r}\, AMF_{2r} \ldots AMF_{nr}) \quad (1)$$

where:

N_{rs} = predicted number of total roadway segment accidents per year after application of accident modification factors;
N_{br} = predicted number of total roadway segment accidents per year for nominal or base conditions;
$AMF_{1r} \ldots AMF_{nr}$ = accident modification factors for roadway segments;
C_r = calibration factor for roadway segments developed for use for a particular geographical area.

The formula shown in Equation (1) allows the AMF for each geometric design and traffic control element to be based solely on the most reliable information concerning the safety effects of that particular element. The best method for considering the safety effects of lane width can be selected as the basis for the AMF without being constrained by the treatment or lane width in the base model or by the formulation of any other AMF.

At-Grade Intersections

Accident frequencies for intersections are predicted with Equation (2).

The safety prediction procedure for at-grade intersections estimates the expected total annual *intersection-related* accident frequency, including those accidents that occur at or near a particular intersection and occur because of the presence of the intersection. The general formula for predicting the safety performance of an intersection is presented below:

$$N_{int} = N_{bi}\, C_i\, (AMF_{1i}\, AMF_{2i} \ldots AMF_{ni}) \quad (2)$$

where:

N_{int} = predicted number of total intersection-related accidents per year after application of accident modification factors;

N_{bi} = predicted number of total intersection-related accidents per year for nominal or base conditions;

$AMF_{1i} \ldots AMF_{ni}$ = accident modification factors for intersections.

C_i = calibration factor for at-grade intersections developed for use for a particular geographical area.

Combining Safety Predictions for an Entire Two-Lane Highway Facility or Project

The total predicted accident frequency for any two-lane highway facility or project can be estimated as the sum of the predicted frequency of nonintersection-related accidents for each of the roadway segments and the predicted frequency of intersection-related accidents for each of the at-grade intersections that make up the project. The general formula for predicting the frequency of accidents for an entire project is presented below:

Accident frequencies for an entire project are combined with Equation (3).

$$N_t = \sum_{\substack{\text{all} \\ \text{segments}}} N_{rs} + \sum_{\substack{\text{all} \\ \text{intersections}}} N_{int} \tag{3}$$

where:

N_{rs} = predicted number of total roadway segment accidents per year after application of accident modification factors;

N_{int} = predicted number of total intersection-related accidents per year after application of accident modification factors;

N_t = predicted accident frequency for an entire project or an extended highway section;

Accident Severity and Accident Type Distributions

In addition to predicting of accident frequency based on Equations (1) and (2), the safety prediction procedure provides estimates of the accident severity and accident type distributions for roadway segments and at-grade intersections. Exhibits 2 and 3 present default estimates of the accident severity and accident type distributions, respectively, that are used in the safety prediction procedure. The default accident severity and accident type distributions in Exhibits 2 and 3 are based on data from the FHWA Highway Safety Information System (HSIS) for four states (Illinois, Michigan, Minnesota, and North Carolina). These default distributions for accident severity and accident type should be replaced with data suitable for the two-lane highway system of a particular state or highway agency as part of the calibration process described in Appendix A.

EXHIBIT 2. DEFAULT DISTRIBUTION FOR ACCIDENT SEVERITY LEVEL ON RURAL TWO-LANE HIGHWAYS

Accident severity distributions are estimated with Exhibit 2.

	Percentage of total accidents			
Accident severity level	Roadway segments[a]	Three-leg STOP-controlled intersections[b]	Four-leg STOP-controlled intersections[b]	Four-leg signalized intersections[b]
Fatal	1.3	1.1	1.9	0.4
Incapacitating Injury	5.4	5.0	6.3	4.1
Nonincapacitating injury	10.9	15.2	12.8	12.0
Possible injury	14.5	18.5	20.7	21.2
Total fatal plus injury	32.1	39.8	41.7	37.7
Property damage only	67.9	60.2	58.3	62.3
TOTAL	100.0	100.0	100.0	100.0

[a] Based on HSIS data for Illinois (1992), Michigan (1995), Minnesota (1996), and North Carolina (1995).

[b] Based on HSIS data for Michigan (1995) and Minnesota (1996).

Accident type and manner of collision distributions are estimated with Exhibit 3.

EXHIBIT 3. DEFAULT DISTRIBUTION FOR ACCIDENT TYPE AND MANNER OF COLLISION ON RURAL TWO-LANE HIGHWAYS.

Accident type and manner of collision	Percentage of total accidents			
	Roadway segments[a]	Three-leg STOP-controlled intersections[b]	Four-leg STOP-controlled intersections[b]	Four-leg signalized intersections[b]
SINGLE-VEHICLE ACCIDENTS				
Collision with animal	30.9	2.1	0.6	0.3
Collision with bicycle	0.3	0.7	0.3	1.0
Collision with parked vehicle	0.7	0.1	0.1	0.1
Collision with pedestrian	0.5	0.4	0.2	1.3
Overturned	2.3	2.1	0.6	0.4
Ran off road	28.1	10.4	4.5	1.9
Other single-vehicle accident	3.6	3.9	1.4	1.6
Total single-vehicle accidents	66.3	19.7	7.7	6.6
MULTIPLE-VEHICLE ACCIDENTS				
Angle collision	3.9	29.8	51.4	28.5
Head-on collision	1.9	2.0	1.4	1.8
Left-turn collision	4.2	6.4	5.9	9.0
Right-turn collision	0.6	0.4	0.2	0.4
Rear-end collision	13.9	26.2	17.2	36.2
Sideswipe opposite-direction collision	2.4	2.9	1.7	2.0
Sideswipe same-direction collision	2.6	4.5	4.4	5.5
Other multiple-vehicle collision	4.1	8.1	10.1	10.0
Total multiple-vehicle accidents	33.7	80.3	92.3	93.4
TOTAL ACCIDENTS	100.0	100.0	100.0	100.0

[a] Based on HSIS data for Illinois (1992), Michigan (1995), Minnesota (1996), and North Carolina (1995).
[b] Based on HSIS data for Michigan (1995) and Minnesota (1996).

SAFETY PREDICTION PROCEDURE FOR ROADWAY SEGMENTS

The general formula for predicting accident frequency on roadway segments is shown in Equation (1). The effect of average daily traffic (ADT) on predicted accident frequency is incorporated through the base models, while the effects of geometric design and traffic control features are incorporated through the AMFs.

Base Model for Roadway Segments

Equation (4) presents the base model for roadway segments developed in research.

The base model for roadway segments is presented below:

$$N_{br} = EXPO\ exp(0.6409 + 0.1388STATE - 0.0846LW - 0.0688RHR + 0.0084DD)$$
$$(\textstyle\sum WH_i exp(0.0450DEG_i))(\textstyle\sum WV_i exp(0.4652K_j))(\textstyle\sum WG_i exp(0.1048GR_i)) \quad (4)$$

where:
- N_{br} = predicted number of total accidents per year on a particular roadway segment;
- $EXPO$ = exposure in million vehicle-miles of travel per year = (ADT)(365)(L)(10^{-6});
- ADT = average daily traffic volume (veh/day) on roadway segment;
- L = length of roadway segment (mi);
- $STATE$ = location of roadway segment (0 in Minnesota, 1 in Washington);
- LW = lane width (ft); average lane width if the two directions of travel differ;

SW = shoulder width (ft); average shoulder width if the two directions of travel differ;
RHR = roadside hazard rating; this measure takes integer values from one to seven and represents the average level of hazard in the roadside environment along the roadway segment. (For definitions of the roadside hazard rating categories, see Appendix C; for the development of the roadside hazard ratings);
DD = driveway density (driveways per mi) on the roadway segment;
WH_i = weight factor for the ith horizontal curve in the roadway segment including driveways on both sides of the road; the proportion of the total roadway segment length represented by the portion of the ith horizontal curve that lies within the segment. (The weights, WH_i, must sum to 1.0.);
DEG_i = degree of curvature for the ith horizontal curve in the roadway segment (degrees per 100 ft);
WV_j = weight factor for the jth crest vertical curve in the roadway segment; the proportion of the total roadway segment length represented by the portion of the jth crest vertical curve that lies within the segment. (The weights, WV_j, must sum to 1.0.);
K_j = crest vertical curve grade rate for the jth crest vertical curve within the roadway segment in percent change in grade per 100 ft $= |g_{j2}-g_{j1}|/l_j$;
g_{jl}, g_{j2} = roadway grades at the beginning and end of the jth vertical curve (percent);
l_j = length of the jth vertical curve (in hundreds of feet);
WG_k = weight factor for the kth straight grade segment; the proportion of the total roadway segment length represented by the portion of the kth straight grade segment that lies within the segment. (The weights, WG_k, must sum to 1.0.); and
GR_k = absolute value of grade for the kth straight grade on the segment (percent).

When the safety prediction procedure is employed for any specified roadway section, Equation (4) is used in the following manner:

- Compute the exposure variable (EXPO) in million vehicle-miles of travel using the actual ADT and segment length (L) for the roadway section and a duration of 1 year (365 days). This assures that the accident frequency predicted by the base model has units of accidents per year.
- Set the STATE variable in base model equal to zero, representing Minnesota conditions. This is done for consistency with the base models for three- and four-leg STOP-controlled intersections, both of which are based solely on Minnesota data. It should be noted that the calibration procedure described later in Appendix A can be used to adapt the base models to the safety conditions of any state other than Minnesota. Calibration would even be desirable to apply the algorithm in Minnesota to a time period other than the period for which the base models were developed.
- Set the remaining variables in the model to the following nominal or base conditions:

Lane width (LW)	12 ft
Shoulder width (SW)	6 ft
Roadside hazard rating (RHR)	3
Driveway density (DD)	5 driveways per mi
Horizontal curvature	None
Vertical curvature	None
Grade	Level (0 percent)

When these nominal or base conditions are entered into Equation (4), the result is Equation (5).

Equation (5) presents the base model used in the procedure for roadway segments. Equation (5) is obtained by applying Equation (4) to specified nominal or base conditions.

With the default values given above, the base model in Equation (4) reduces to:

$$N_{br} = (ADT)(L)(365)(10^{-6}) \exp(-0.4865) \qquad (5)$$

Accident Modification Factors for Roadway Segments

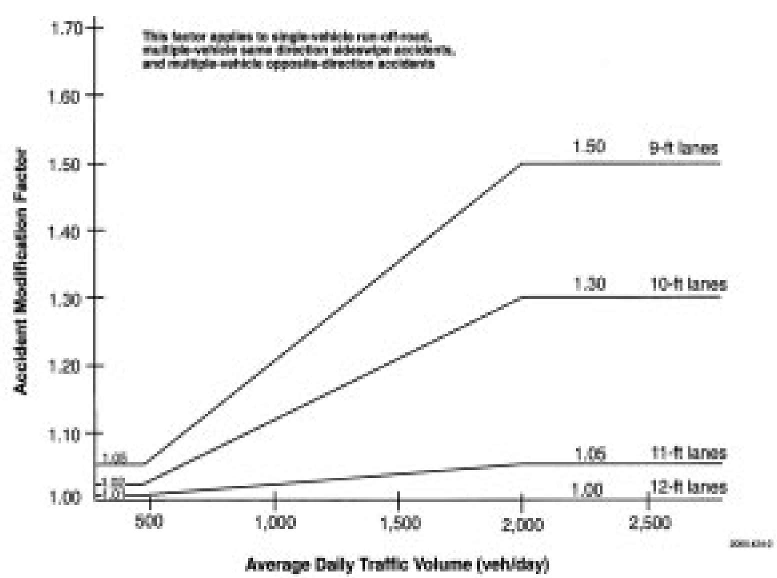
The incremental effects of individual geometric design and traffic control features of roadway segments are represented in the safety prediction procedure by AMFs *(1)*. The AMFs for geometric design and traffic control features of roadway segments are presented below.

Lane Width

Exhibit 4 presents the AMF for lane width.

The nominal or base value of lane width is 12 ft. Thus, 12-ft lanes are assigned an AMF of 1.00. Exhibit 4 illustrates the recommended values of the AMF for lane widths from 9 to 12 ft. The AMF for any lane widths within the range of 9 to 12 ft should be interpolated between the lines shown in Exhibit 4. Lanes less than 9 ft in width are assigned an AMF equal to that for 9-ft lanes. Lanes greater than 12 ft in width are assigned an AMF equal to that for 12-ft lanes. As shown in the exhibit, the AMFs for lanes less than 12 ft in width are constant for all ADTs above 2,000 veh/day, but decrease to a substantially smaller value over the range of traffic volumes between 400 and 2,000 veh/day. The AMFs then have constant, but lower, values in the range of ADT below 400 veh/day.

EXHIBIT 4. ACCIDENT MODIFICATION FACTOR FOR LANE WIDTH



Equation (6) assumes, based on supporting research, that lane width affects only the accident types identified in Exhibit 4.

If the lane widths for the two directions of travel on a roadway segment differ, the AMF should be determined separately for the lane width in each direction of travel and the resulting AMFs should then be averaged.

The AMFs shown in Exhibit 4 apply to single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents. The AMFs expressed on this basis must, therefore, be adjusted to total accidents within the safety prediction methodology. This is accomplished with the following equation:

$$AMF = (AMF_{ra} - 1.0)\, P_{ra} + 1.0 \qquad (6)$$

where:

AMF = accident modification factor for total accidents;

AMF_{ra} = accident modification factor for related accidents (i.e., single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents), such as the accident modification factor for lane width shown in Exhibit 4;

P_{ra} = proportion of total accidents constituted by related accidents.

The proportion of related accidents (P_{ra}) is estimated as 0.35 (i.e., 35 percent) based on the default distribution of accident types presented in Exhibit 3. This default accident type distribution, and therefore the value of P_{ra}, may be changed as part of the calibration process.

The AMFs for lane width are based on the results of Zegeer et al. *(2)* and Griffin and Mak *(3)*.

Shoulder Width and Type

The nominal or base value of shoulder width and type is a 6-ft paved shoulder, which is assigned an AMF value of 1.00. Exhibit 5 illustrates the recommended AMF for shoulder widths that differ from 6 ft. Another AMF, presented below, adjusts for differences between gravel, turf, or composite shoulders and paved shoulders. AMFs for shoulder widths between 0 and 8 ft should be interpolated between the lines in Exhibit 5. Shoulders greater than 8 ft in width should be assigned AMFs equal to those for 8 ft. The AMFs shown in Exhibit 5 apply only to single-vehicle run-off-the-road and opposite-direction accidents. The AMFs for shoulder width and type are based on the results of Zegeer et al. *(2, 4)*

The nominal or base condition for shoulder type is the paved shoulder. Exhibit 6 presents the recommended AMFs for gravel, turf, and composite shoulders as a function of shoulder width.

EXHIBIT 5. ACCIDENT MODIFICATION FACTOR FOR SHOULDER WIDTH

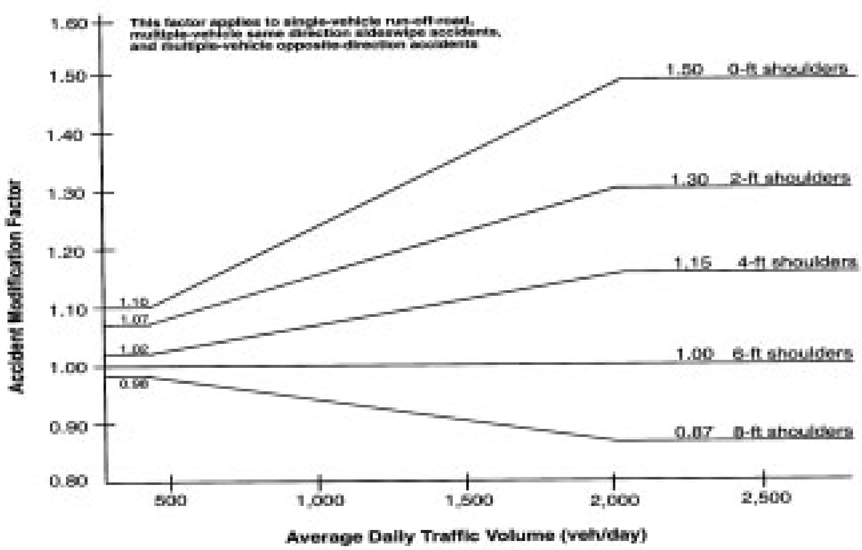


Exhibit 5 presents the AMF for shoulder width.

Exhibit 6 presents the AMFs for shoulder type as a function of shoulder width.

EXHIBIT 6. ACCIDENT MODIFICATION FACTORS FOR SHOULDER TYPES ON TWO-LANE HIGHWAYS

Shoulder type	Shoulder width (ft)							
	0	1	2	3	4	6	8	10
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.03
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06	1.07
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11	1.14

Note: The values for composite shoulders in this table represent a shoulder for which 50 percent of the shoulder width is paved and 50 percent of the shoulder width is turf.

If the shoulder types and/or widths for the two directions of travel on a roadway segment differ, the AMF should be determined separately for the shoulder type and width in each direction of travel and the resulting AMFs should then be averaged.

The AMFs for shoulder width and type apply only to single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents. The AMFs expressed on this basis must, therefore, be adjusted to total accidents within the safety prediction methodology. This can be accomplished with the following equation that is analogous to Equation (6):

Equation (7) assumes, based on supporting research, that shoulder type and width affect only the accident types identified in Exhibit 5.

$$AMF = (AMF_{wra}\ AMF_{tra} - 1.0)\ P_{ra} + 1.0 \tag{7}$$

where:

AMF_{wra} = accident modification factor for related accidents based on shoulder width (from Exhibit 5);

AMF_{tra} = accident modification factor for related accidents based on shoulder type (from Exhibit 6); and

P_{ra} = proportion of total accidents constituted by related accidents.

The proportion of related accidents (P_{ra}) is estimated as 0.35 (i.e., 35 percent) based on the default distribution of accident types presented in Exhibit 2. This default accident type distribution and therefore the value of P_{ra}, may be changed by a highway agency as part of the calibration process.

Horizontal Curves

Length, Radius, and Presence or Absence of Spiral Transitions

The nominal or base condition for horizontal alignment is a tangent roadway section. An AMF has been developed to represent the manner in which accident experience of curved alignments differs from that of tangents. This AMF applies to total roadway segment accidents, not just the related accident types considered for lane and shoulder widths.

The AMF for horizontal curves has been determined from the regression model developed by Zegeer et al. *(5)*.

Equation (8) is used to determine the AMF for horizontal curve length, radius, and the presence or absence of spiral transitions.

The AMF for horizontal curvature is in the form of an equation and, thus, might be termed an accident modification function rather than an accident modification factor. The AMF for length, radius, and presence or absence of spiral transitions on horizontal curves is:

$$AMF = \frac{1.55L_c + \dfrac{80.2}{R} - 0.012S}{1.55L_c} \tag{8}$$

where:

L_c = length of horizontal curve (mi);
R = radius of curvature (ft); and
S = 1 if spiral transition curve is present
0 if spiral transition curve is not present.

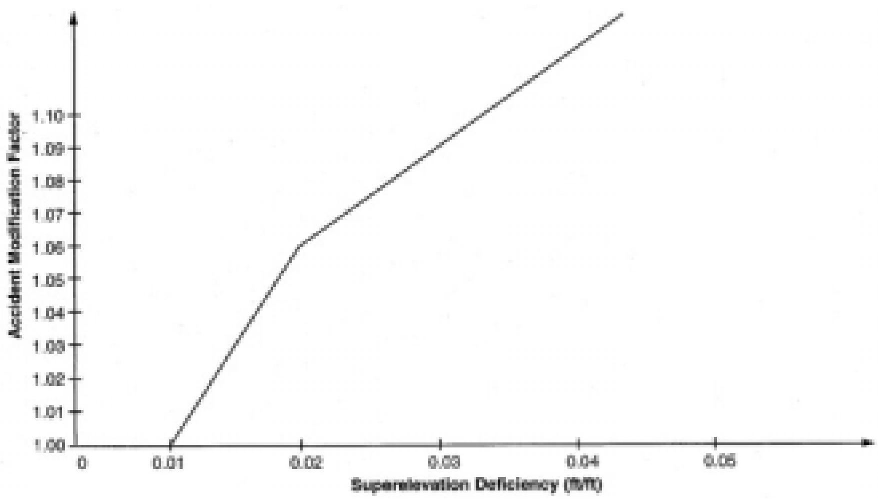
In applying the accident modification functions for curves with spiral transitions, the length variable (L_c) should represent the length of the circular portion of the curve plus the length of the spiral transition.

Superelevation

The nominal or base condition for the AMF for the superelevation of a horizontal curve is the amount of superelevation recommended by the AASHTO Green Book *(5)*. The superelevation recommended by the AASHTO Green Book is determined taking into account the value of maximum superelevation rate, e_{max}, established by highway agency policies. Policies concerning maximum superelevation rates for horizontal curves vary between highway agencies based on climate and other considerations. If no value of e_{max} specified, then e_{max} = 0.06 could be assumed. The AMF for superelevation is based on the superelevation deficiency of a horizontal curve (i.e., the difference between the actual superelevation and the superelevation recommended by AASHTO policy). When the actual superelevation meets or exceeds that recommended by AASHTO policy, the value of the superelevation AMF is 1.00. There is no effect of superelevation deficiency on safety until the superelevation deficiency exceeds 0.01.

Exhibit 7 presents an AMF for horizontal curves for which the actual super-elevation is more than 0.01 below the design super-elevation recommended by AASHTO policy.

EXHIBIT 7. ACCIDENT MODIFICATION FACTOR FOR SUPERELEVATION DEFICIENCY



The general functional form of an AMF for superelevation is shown in Exhibit 7, based on the work of Zegeer et al. *(6, 7)*. For a horizontal curve with 12-ft lanes and no spiral transitions, an AMF is suggested of the form:

Superelevation and superelevation deficiency are presented as ratios (i.e., 0.01), not as percentages (i.e., 1.0 percent).

$$AMF = \frac{1.22 + \frac{1604}{R} - 9.52SD}{1.22 + \frac{1604}{R}} \quad (9)$$

where:

SD = superelevation deficiency (ft/ft).

However, the AMF in the form shown in Equation (9) is not directly usable because it suggests that for any given superelevation deficiency, the value of AMF increases with increasing radius of curvature. In fact, it seems likely that the opposite should occur, with superelevation deficiencies being more important on curves with smaller radii. Equation (9) was determined using a mean radius of horizontal curves of 842.5 ft. Exhibit 8 presents the AMF values obtained using Equation (9) for that particular mean radius.

EXHIBIT 8. AMF VALUES FOR HORIZONTAL CURVES HAVING MEAN RADIUS OF 842.5 FT

Superelevation deficiency	AMF
0.02	1.06
0.03	1.09
0.04	1.12
0.05	1.15

Based on these values, the following relationships which form the basis for Exhibit 7 can be derived:

The AMF for superelevation deficiency is determined with Equations (10) through (12)

$$AMF = 1.00 \text{ for } SD < 0.01 \quad (10)$$

$$AMF = 1.00 + 6\,(SD - 0.01) \text{ for } 0.01 \leq SD < 0.02 \quad (11)$$

$$AMF = 1.06 + 3\,(SD - 0.02) \text{ for } \geq 0.02 \quad (12)$$

This AMF applies to total roadway segment accidents for roadway segments located on horizontal curves.

Grades

The AMF for roadway grade applies to the entire grade segment from PVI to PVI. There is no explicit consideration of vertical curves.

The nominal or base condition for grade is a level roadway (0% grade). Exhibit 9 presents the accident modification factor for grades based on an analysis of two-lane highway grades in Utah conducted by Miaou *(8)*. The AMFs in Exhibit 9 are applied to each individual grade section on the roadway being evaluated without respect to the sign of the grade. The sign of the grade is irrelevant because each grade on a two-lane highway is an upgrade for one direction of travel and a downgrade for the other. The grade factors are applied to the entire grade from one point of vertical intersectional (PVI) to the next (i.e., there is no special account taken of vertical curves). The AMFs in Exhibit 9 apply to total roadway segment accidents.

Exhibit 9 presents the AMF for roadway grade.

EXHIBIT 9. ACCIDENT MODIFICATION FACTORS FOR GRADE OF ROADWAY SECTIONS

Grade (%)				
0	2	4	6	8
1.00	1.03	1.07	1.10	1.14

Note: This factor can be expressed as an effect of 1.6 percent per percent grade.

Driveway Density

The nominal or base condition for driveway density is five driveways per mi. The AMF for driveway density is based on the following equation derived from the work of Muskaug *(9)*:

Equation (13) is used to determine the AMF for driveway density.

$$AMF = \frac{0.2 + [0.05 - 0.005\ln(ADT)]DD}{0.2 + [0.05 - 0.005\ln(ADT)](5)} \qquad (13)$$

where:

ADT = annual average daily traffic volume of the roadway being evaluated (veh/day); and
DD = driveway density for both sides of the road combined (driveways per mile).

Equation (13) can be applied to total roadway accidents of all severity levels.

Passing Lanes

The AMF for a passing lane in one direction of travel is 0.75.

The nominal or base condition for passing lanes is the absence of a passing lane (i.e., the normal two-lane cross section). The AMF for a conventional passing or climbing lane added in one direction of travel on a two-lane highway is 0.75 for total accidents in both directions of travel over the length of the passing lane from the upstream end of the lane addition taper to the downstream end of the lane drop taper. This value assumes that the passing lane is operationally warranted and that the length of the passing lane is appropriate for the operational conditions on the roadway. There may also be some safety benefit on the roadway downstream of a passing lane, but this effect has not been quantified.

The AMF for side-by-side passing lanes (i.e., passing lanes in both directions of travel) is 0.65.

The AMF for short four-lane sections (i.e., side-by-side passing lanes provided in opposite directions on the same roadway section) is 0.65 for total accidents over the length of the short four-lane section. This AMF applies to any portion of roadway where the cross section has four lanes and where both added lanes have been provided over a limited distance to increase passing opportunities. This AMF does not apply to extended four-lane highway sections.

The AMF for passing lanes is based primarily on the work of Harwood and St. John *(10)*, with consideration also given to the results of Rinde *(11),* and Nettleblad *(12)*. The AMF for short four-lane sections is based on the work of Harwood and St. John *(10)*. These AMFs apply to total roadway segment accidents within the passing lane and short four-lane sections.

Two-Way Left-Turn Lanes

Equation (14) is used to determine the AMF for the presence of a center two-way left-turn lane.

The installation of a center two-way left-turn lane (TWLTL) on a two-lane highway to create a three-lane cross section can reduce accidents related to turning maneuvers at driveways. The AMF for installation of a TWLTL is:

$$AMF = 1 - 0.7\ P_D\ P_{LT/D} \qquad (14)$$

where:

P_D = driveway-related accidents as a proportion of total accidents; and
$P_{LT/D}$ = left-turn accidents susceptible to correction by a TWLTL as a proportion of driveway-related accidents.

The value of P_D can be estimated using the following equation: *(13)*

$$P_D = \frac{0.0047DD + 0.0024DD^2}{1.199 + 0.0047DD + 0.0024DD^2} \qquad (15)$$

The value of $P_{LT/D}$ is estimated as 0.5.

Equation (14) provides the best estimate of the AMF for TWLTL installation that can be made without data on the left-turn volumes within the TWLTL. Realistically, such volumes are seldom available for use in such analyses. This AMF applies to total roadway segment accidents.

The AMF for TWLTL installation should be set equal to 1.00 if the driveway density is less than five driveways per mi.

The AMF for TWLTL installation should not be applied unless the driveway density is greater than or equal to five driveways per mi. If the driveway density is less than five driveways per mi, the AMF for TWLTL installation is 1.00. TWLTL installation would, in any case, be inappropriate for roadway segments with driveway densities lower than this threshold.

Roadside Design

The quality of roadside design is rated on a 1 to 7 scale, as illustrated in Appendix C.

For purposes of the safety prediction methodology, the quality of roadside design is represented by the roadside hazard rating (1 to 7 scale) developed by Zegeer et al. *(2)*. The AMF for roadside design was derived directly from the base model for roadway sections presented in Equation (4). The nominal or base value of roadside hazard rating employed in the base model for roadway sections is three. The AMF is based on the ratio of the accident experience predicted by base model using the actual roadway section in question to the accident experience predicted by the base model using the nominal value of roadside hazard rating equal to three. The AMF is:

Equation (16) is used to determine the AMF for roadside design.

$$AMF = \frac{exp(-0.6869 + 0.0668RHR)}{exp(-0.4865)} \quad (16)$$

where:

RHR = Roadside Hazard Rating (1 to 7 scale).

This AMF applies to total roadway segment accidents. Photographic examples and quantitative definitions for each roadside hazard rating (1 through 7) as a function of roadside design features such as side slope and clear zone width are presented in Appendix C.

Procedure for Determining the Expected Accident Frequency for a Particular Roadway Segment

There are two safety prediction procedures; the selection of the appropriate procedure depends on whether site-specific accident history data are available.

The safety prediction procedure for roadway segments is intended to estimate the expected accident frequency for any specified geometric design alternative on a given roadway segment. This procedure is used when no site-specific accident history data are available. The safety prediction procedure is applicable to planned roadways that have not yet been constructed and to existing roadways where, for whatever reason, site-specific accident history data are not available to the analyst. Another procedure, which is described in more detail in Appendix B, is used when site-specific accident history data are available. This procedure incorporates an Empirical Bayes (EB) approach to combining estimates from the safety prediction procedure and site-specific accident history data. The safety prediction procedure is applied to any specific roadway segment in a series of straight forward steps, described in Section III.

SAFETY PREDICTION PROCEDURE FOR AT-GRADE INTERSECTIONS

The predicted frequency of accidents that occur at or are related to an at-grade intersection is shown in Equation (2). The structure of the safety prediction procedure for at-grade intersections is similar to the procedure for roadway sections.

The effect of traffic volume on predicted accident frequency for at-grade intersections is incorporated through the base models, while the effect of geometric and traffic control features are incorporated through the AMFs. Each of the base models for at-grade intersections incorporates separate effects for the ADTs on the major- and minor-road legs, respectively.

Separate base models have been formulated for three-leg intersections with STOP control, four-leg intersections with STOP control, and four-leg signalized intersections. The AMFs used in the safety prediction procedure for these three intersection types also differ, but the algorithms for all three intersection types are structured as shown in

Equation (2). The base models for at-grade intersections and the AMFs for at-grade intersections are presented below.

Base Models for At-Grade Intersections

Base models have been developed for three types of at-grade intersections on rural two-lane highways. These are:

- Three-leg intersections with STOP control on the minor-road approach
- Four-leg intersections with STOP control on the minor-road approach
- Four-leg signalized intersections

The effect of all-way STOP control on safety is accounted for with an AMF, presented later in this section, rather than with the base models.

Intersection models are based on all intersection-related accidents that occur within 250 ft of the intersection.

The base models for each of these intersection types predict total accident frequency per year for intersection-related accidents within 250 ft of a particular intersection. These models address intersections that have only two lanes on both the major- and minor-road legs. The base models for each of the three intersection types are presented below.

Three-Leg STOP-Controlled Intersections

The base model for three-leg intersections with STOP control on the minor-road leg is presented below:

Equation (17) presents the base model for three-leg STOP-controlled intersections developed in research

$$N_{bi} = exp(-11.28 + 0.79 lnADT_1 + 0.49 lnADT_2 + 0.19 RHRI + 0.28 RT) \quad (17)$$

where: ADT_1 = average daily traffic volume (veh/day) on the major road;
ADT_2 = average daily traffic volume (veh/day) on the minor road;
$RHRI$ = roadside hazard rating within 250 ft of the intersection on the major road [see description of the variable RHR in Equation (4)]; and
RT = presence of right-turn lane on the major road (0 = no right-turn lane present; 1 = right-turn lane present).

This model predicts the total intersection-related accident frequency for three-leg intersections with minor-road STOP control for which the independent variables shown in Equation (17) are known *(1)*.

When the safety prediction procedure is employed to predict the expected accident frequency for any specified three-leg STOP-controlled intersection on a two-lane highway, Equation (17) is used in the following manner:

- The traffic volume variables (ADT_1 and ADT_2) are set equal to the actual ADTs of the major- and minor-road legs. If the ADTs differ between the two major-road legs, they should be averaged.
- The remaining variables in the model should be set equal to the following nominal or base conditions:

Roadside hazard rating (RHRI)	2
Presence of right-turn lane on the major road (RT)	None present (0)

With the default values of given above, the base model in Equation (17) reduces to:

Equation (18) presents the base model used in the procedure for three-leg STOP-controlled intersections. Equation (18) is obtained by applying Equation (17) to specified nominal or base conditions.

$$N_{bi} = exp(-10.9 + 0.79 lnADT_1 + 0.49 lnADT_2) \quad (18)$$

Equation (19) presents the base-model for four-leg STOP-controlled intersections developed in research.

Four-Leg STOP-Controlled Intersections

The base model for four-leg intersections with STOP control is presented below:

$$N_{bi} = exp(-9.34 + 0.60 lnADT_1 + 0.61 lnADT_2 + 0.13 ND_1 - 0.0054 SKEW_4) \quad (19)$$

where:

ND_1 = number of driveways on the major-road legs within 250 ft of the intersection; and

$SKEW_4$ = intersection angle (degrees) expressed as one-half of the angle to the right minus one-half of the angle to the left for the angles between the major-road leg in the direction of increasing stations and the right and left legs, respectively.

This model predicts the total intersection-related accident frequency for any four-leg intersection with minor-road STOP control for which the independent variables shown in Equation (19) are known *(1)*.

When the safety prediction procedure is employed to predict the expected accident frequency for any specified four-leg STOP-controlled intersection on a two-lane highway, Equation (19) is used in the following manner:

Equation (20) presents the base model used in the procedure for four-leg STOP-controlled intersections. Equation (20) is obtained by applying Equation (19) to specified nominal or base conditions.

- The traffic volume variables (ADT1 and ADT2) are set equal to the actual ADTs of the major- and minor-road legs, respectively. If the ADTs differ between either the two major- or minor-road legs, they should be averaged.
- The remaining variables in the model should be set equal to the following nominal or base conditions:

Number of driveways within 250 ft of the intersection on the major road (ND_1)	No driveways
Intersection skew angle ($SKEW_4$)	0 degrees

With the default values of ND_1 and $SKEW_4$ given above, the base model in Equation (19) reduces to:

$$N_{bi} = exp(-9.34 + 0.60 lnADT_1 + 0.61 lnADT_2) \quad (20)$$

Equation (21) presents the base model for four-leg signalized intersections developed in research.

Four-Leg Signalized Intersections

The base model for four-leg signalized intersections is presented below:

$$N_{bi} = exp(-5.46 + 0.60 lnADT_1 + 0.20 lnADT_2 - 0.40 PROTLT - 0.018 PCTLEFT_2 + 0.11 VEICOM + 0.026 PTRUCK + 0.041 ND_1) \quad (21)$$

where:

$PROTLT$ = presence of protected left-turn signal phase on one or more major-road approaches; = 1 if present; = 0 if not present

$PCTLEFT_2$ = percentage of minor-road traffic that turns left at the signal during the morning and evening peak hours combined

$VEICOM$ = grade rate for all vertical curves (crests and sags) within 250 ft of the intersection along the major and minor roads

$PTRUCK$ = percentage of trucks (vehicles with more than four wheels) entering the intersection for the morning and evening peak hours combined

ND_1 = number of driveways within 250 ft of the intersection on the major road.

This model predicts total intersection-related accident frequency for any four-leg signalized intersection for which the independent variables shown in Equation (21) are known. The model predictions are reliable only within the ranges of independent variables for which data were available in the data base used to develop the model *(1)*.

When the accident prediction model is employed to predict the expected accident frequency for any specified four-leg intersection on a two-lane highway, Equation (21) is used in the following manner:

- The traffic volume variables (ADT_1 and ADT_2) are set equal to the actual ADTs of the major- and minor-road legs, respectively. If the ADTs differ between either the major- or minor-road legs, they should be averaged.
- The remaining variables in the model should be set equal to the following nominal or base conditions:

Presence of protected left-turn signal phase (PROTLT)	No left-turn phase
Percentage of minor-road traffic turning left ($PCTLEFT_2$)	28.4 percent
Grade rate for vertical curves within 76 m (250 ft) of the intersection (VEICOM)	No vertical curves
Percentage of trucks entering the intersection (PTRUCK)	9.0 percent
Number of driveways within 76 m (250 ft) of the intersection on the major road (ND_1)	0 driveways

With the nominal or base values of PROTLT, $PCTLEFT_2$, VEICOM, and PTRUCK given above, the base model in Equation (21) reduces to:

Equation (22) presents the base model actually used in the procedure for four-leg signalized intersections. Equation (22) is obtained by applying Equation (21) to specified nominal or base conditions.

$$N_{bi} = exp(-5.73 + 0.60 lnADT_1 + 0.20 lnADT_2) \quad (22)$$

Accident Modification Factors for At-Grade Intersections

The AMFs for geometric design and traffic control features of at-grade intersections are presented below.

Intersection Skew Angle

The nominal or base condition for intersection skew angle is 0 degrees of skew (i.e., an intersection angle of 90 degrees). The skew angle for an intersection was defined as the deviation from an intersection angle of 90 degrees and carries a positive or negative sign that indicates whether the minor road intersects the major road at an acute or obtuse angle. This sign was introduced into the base model because a Finnish study by Kulmala found that acute and obtuse skew angles affected safety differently *(14)*.

Intersection skew angle represents the angle between the major- and minor-road legs. The sign of the angle distinguishes between acute and obtuse angles.

STOP-Controlled Intersections

The AMF for intersection angle at three-leg STOP-controlled intersections is derived from the base model for this intersection type:

$$N_{bi} = \frac{exp(-12.15 + 1.001 lnADT_1 + 0.406 lnADT_2 + 0.0040 SKEW_3)}{exp(-12.15 + 1.001 lnADT_1 + 0.406 lnADT_2)} \quad (23)$$

where:

ADT_1 = average daily traffic volume for the major road;
ADT_2 = average daily traffic volume for the minor road; and
$SKEW_3$ = intersection angle (degrees) minus 90 for the angle between the major-road leg in the direction of increasing stations and a leg to the right; 90 minus intersection angle (degrees) for the angle between the major-road leg in the direction of increasing stations and a leg to the left.

Equation (23) reduces to:

$$AMF = exp(0.004 SKEW_3) \quad (24)$$

The AMF for intersection angle at four-leg STOP-controlled intersections is based directly on the base model presented as Equation (19) for this intersection type:

$$N_{bi} = \frac{exp(-9.34 + 0.60 lnADT_1 + 0.61 lnADT_2 + 0.13 ND_1 - 0.0054 SKEW_4)}{exp(-9.34 + 0.60 lnADT_1 + 0.61 lnADT_2)} \quad (25)$$

where:

$SKEW_4$ = intersection angle (degrees) expressed as one-half of the angle to the right minus one-half of the angle to the left for the angles between the major-road leg in the direction of increasing stations and the right and left legs, respectively

Equation (25) reduces to:

$$AMF = exp(-0.0054 SKEW_4) \quad (26)$$

Equations (27) and (28) are used to determine the AMFs for intersection skew angle at three- and four-leg STOP-controlled intersections, respectively.

Positive and negative skew angles (as defined above for available $SKEW_3$ and $SKEW_4$) are considered to have similar detrimental effect to safety. Therefore, Equations (24) and (26) have been recast as shown below. For a three-leg STOP-controlled intersection:

$$AMF = exp(0.004 SKEW_3) \quad (27)$$

For a four-leg STOP-controlled intersection:

$$AMF = exp(0.0054 SKEW_4) \quad (28)$$

where:

$SKEW$ = intersection skew angle (degrees), expressed as the absolute value of the difference between 90 degrees and the actual intersection angle.

The AMF for intersection skew angle is 1.00 for all signalized intersections.

These AMFs apply to total intersection accidents.

Signalized Intersections

Skew angle is a much less important factor in the operation of signalized intersection than in the operation of STOP-controlled intersections. Since the traffic signal separates most movements from conflicting approaches, the risk of collisions related to the skew angle between the intersecting approaches is limited at a signalized intersection; therefore, the AMF for skew angle at four-leg signalized intersections is 1.00 for all cases.

Intersection Traffic Control

The AMF for all-way STOP-controlled intersections is 0.53.

The safety differences between STOP-controlled and signalized intersections are accounted for by use of separate base models rather than by an AMF. However, an AMF for the difference between minor-leg and all-way STOP-controlled intersections has been developed and is discussed below. The nominal base case for STOP-controlled intersections has STOP signs on the minor leg(s) only. An AMF is provided for intersection with all-way STOP control. Minor-road YIELD controlled intersections are treated identically to minor-road STOP-controlled intersections in the safety prediction methodology.

All-way STOP control is most appropriate for roadways with relatively equal traffic volumes on all legs of the intersection. The *Manual on Uniform Traffic Control Devices* (MUTCD) includes specific warrants for all-way STOP control *(15)*. All-way STOP control should not be considered for an intersection unless these warrants are met. The AMF for conversion from minor-road to all-way STOP-control is 0.53. This AMF applies to total intersection-related accidents. The AMF value of 0.53 implies that an all-way STOP-controlled intersection experiences 47 percent fewer accidents than a two-way STOP-controlled intersection. This AMF is based on the findings of Lovell and Hauer *(16)*.

Intersection Left-Turn Lanes

The nominal or base condition for intersection left-turn lanes is the absence of left-turn lanes on the major-road approaches. The AMFs for presence of left-turn lanes on the major road are presented in Exhibit 10. These AMFs apply to total intersection-related accidents. The AMFs for installation of left-turn lanes are based on the best judgment of an expert panel from review of a number of studies *(17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28)*. The AMFs for installation of left-turn lanes on both approaches to a four-leg intersection are equal to the square of the corresponding AMF for installation of a left-turn lane on a single approach. No data are available to quantify the effect on safety of left-turn lanes on a minor road, so these will not be considered in the safety prediction methodology.

Exhibit 10 presents the AMFs for major-road left-turn lanes at intersections.

EXHIBIT 10. ACCIDENT MODIFICATION FACTORS FOR INSTALLATION OF LEFT-TURN LANES ON THE MAJOR-ROAD APPROACHES TO INTERSECTION ON TWO-LANE RURAL HIGHWAYS.

Intersection type	Intersection traffic control	Number of major-road approaches on which left-turn lanes are installed	
		One approach	Both approaches
Three-leg intersection	STOP sign[a]	0.56	–
	Traffic signal	0.85	–
Four-leg intersection	STOP sign[a]	0.72	0.52
	Traffic signal	0.82	0.67

[a] STOP signs on minor-road approach(es).

Intersection Right-Turn Lanes

The AMFs for major-road right-turn lanes at unsignalized intersections are 0.86 for one approach and 0.74 for both approaches. The AMFs for signalized intersections are half of those for unsignalized intersections.

The nominal or base condition for intersection right-turn lanes is the absence of right-turn lanes on the major-road approaches. The AMF for the presence of right-turn lanes at STOP-controlled intersections is 0.86 for a right-turn lane on one major-road approach and 0.74 for right-turn lanes on both major road approaches. These AMFs apply to total intersection-related accidents. The values of the AMFs are based on a judgment by an expert panel based on the work of Vogt and Bared *(29, 30, 31)*, Kulmala *(13)*, and Elvik *(32)*. Also, no effect is considered for the provision of a paved shoulder on an intersection approach unless that paved shoulder is marked as a right-turn lane.

The effectiveness of right-turn lanes at signalized intersections should be estimated as half that found at STOP-controlled intersections. Thus, the AMF for the presence of right-turn lanes at signalized intersections is 0.93 for a right-turn lane on one major-road approach and 0.87 for right-turn lanes on both major-road approaches. These AMFs also apply to total intersection-related accidents.

Intersection Sight Distance

The nominal or base condition for intersection sight distance is the availability of adequate intersection sight distance along the major road in all quadrants of the intersection. The AMFs for intersection sight distance at intersections with STOP control on the minor leg(s) are:

The AMFs for limited intersection sight distance are presented here.

- 1.05 if sight distance is limited in one quadrant of the intersection.
- 1.10 if sight distance is limited in two quadrants of the intersection.
- 1.15 if sight distance is limited in three quadrants of the intersection.
- 1.20 if sight distance is limited in four quadrants of the intersection.

Intersection sight distance is considered limited if the available sight distance is less than the sight distance specified by AASHTO policy for a design speed 10 mi/h less than the major-road design speed.

These AMFs apply to total intersection-related accidents.

Sight distance in a quadrant is considered limited if the available sight distance is less than the sight distance specified by AASHTO policy for a design speed of 10 mi/h less than the major-road design speed. Only sight distance restrictions due to roadway alignment and terrain are considered by the safety prediction methodology. Sight distance restrictions due to specific obstructions (e.g., trees, bushes, poles, and buildings) are not considered.

The AMFs for intersection sight distance apply only to two-way STOP-controlled or YIELD-controlled intersections. An AMF of 1.00 is applicable to signal-controlled and all-way STOP-controlled intersections.

The recommended AMF was determined from the best judgment of an expert panel based on the results of Kulmala *(14)*, Brüde and Larsson *(33)*, and Elvik *(32)*.

Procedure for Determining the Expected Accident Frequency for a Particular At-Grade Intersection

There are two safety prediction procedures; the selection of the appropriate procedure depends on whether site-specific accident history data are available.

The safety prediction procedure for at-grade intersections is intended to estimate the expected accident frequency at a given intersection. This procedure is used when no site-specific accident history data are available. The safety prediction procedure is applicable to planned intersections that have not yet been constructed and to existing intersections where, for whatever reason, site-specific accident history data are not available to the analyst. Another procedure, which is described in more detail in Appendix B, is used when site-specific accident history data are available. This procedure incorporates an Empirical Bayes (EB) approach to combining estimates from the safety prediction procedure and site-specific accident history data. The safety prediction procedure is applied to any specific at-grade intersection in a series of straight forward steps, described in Section III.

SAFETY PREDICTION PROCEDURE FOR AN ENTIRE PROJECT

The predicted accident frequency for an entire project is determined by summing the accident frequencies for all roadway segments and intersections that make up the project.

The total predicted accident frequency for an entire project or an extended highway section can be determined by summing the accidents predicted for all roadway segments and intersections comprised by the project. Equation (3) presents the formula used to predict accident frequency for an entire project. The accident prediction for roadway segments and intersections are calculated using Equations (1) and (2), respectively.

III. APPLICATIONS

The safety prediction methodology can be used to estimate the expected accident frequency for an entire two-lane highway section or improvement project. Two applications of this methodology are presented in this section. The first application is used when no site-specific accident history data are available. This application is used for planned roadways that have not yet been constructed and for existing roadways when, for whatever reason, enough site-specific accident history data are not available to the analyst. The second application, which is summarized below and presented in more detail in Appendix B, is used when enough site-specific accident history data are available. This procedure incorporates an Empirical Bayes (EB) approach to combining estimates from the safety prediction methodology and site-specific accident history data.

The first application deals with safety prediction when no site-specific accident history data are available.

SAFETY PREDICTION WHEN SITE-SPECIFIC ACCIDENT HISTORY DATA ARE NOT AVAILABLE

The safety prediction methodology is applied to any specific geometric design alternative in a series of steps that can be summarized as follows *(1)*:

This stepwise procedure deals with safety prediction when no site-specific accident data are available.

- Step 1—Define the limits of the project and determine the geometrics of the project for which the expected safety performance is to be predicted.
- Step 2—Divide the project into individual homogeneous roadway segments and intersections.
- Step 3—Determine the geometric design and traffic control features for each individual roadway segment and intersection.
- Step 4—Determine the ADTs for each roadway segment and intersection during each year for which the expected safety performance is to be predicted.
- Step 5—Select an individual roadway segment or intersection for evaluation. If there are no more roadway segments or intersections to be evaluated, go to Step 13.
- Step 6—Select a particular year of the specified evaluation period for the roadway segment or intersection of interest. If there are no more years to be evaluated for that roadway segment or intersection, go to Step 12.
- Step 7—Apply the appropriate base model to determine the predicted accident frequency for nominal or base conditions for the selected year.
- Step 8—Multiply the result obtained in Step 7 by the appropriate calibration factor for a specific state or geographical region.
- Step 9—Multiply the result obtained in Step 8 by the appropriate AMFs representing safety differences between the nominal or base conditions and the actual geometrics and traffic control of the roadway segment or intersection.
- Step 10—Estimate the expected distribution accident severities and accident types for the roadway segment or intersection from the default distributions of accident severity and accident type.
- Step 11—If there is another year to be evaluated for the selected roadway segment or intersection, return to Step 6; otherwise, proceed to Step 12.
- Step 12—If there is another roadway segment or intersection to be evaluated, return to Step 5; otherwise, proceed to Step 13.
- Step 13—Summarize and present the predictions in a useful format for the user.

Exhibit 11 presents a flow diagram of the safety prediction methodology incorporating these steps. The next sections outline in more detail the computation steps and introduces worksheets to estimate the expected accident frequency for roadway segments, at-grade intersections, and entire projects when site specific accident history are not available.

Steps 1 and 2 are presented under the preliminary steps section, and are used when more than one homogeneous roadway segment or at-grade intersection as part of an entire project. Steps 3 through 12 have been separated into two sections, those for roadway segments are designated with the letter "a," while those for at-grade intersections are designated with the letter "b." Step 13 is presented under the entire project section.

Preliminary Steps

Step 1 involves defining limits and determining project geometrics.

Step 1—Define the limits of the project and determine the geometrics of the project for which the expected safety performance is to be predicted.

The project evaluated can represent either an existing roadway or a design alternative for a proposed improvement project. The geometric design features of the project and the traffic control at each intersection must be documented. The geometric design features are determined from either a plan of the existing roadway available in the CAD system or from data entered by the user.

To apply the methodology, the facility must be subdivided into individual homogeneous roadway segments and intersections. A new segment starts where any of the variables listed here changes.

Step 2—Divide the project into individual homogeneous roadway segments and intersections.

The next step is to divide the project into individual homogeneous roadway segments and intersections. The roadway must be divided into homogeneous segments. A new homogeneous segment begins at each location where the value of one of the following variables changes:

- Average daily traffic volume (veh/day)
- Lane width
- Shoulder width and type
- Driveway density (driveway per mile)
- Roadside hazard rating

Also, a new homogeneous segment starts at any of the following locations:

- Intersection
- Beginning or end of a horizontal curve
- Point of vertical intersection (PVI) for a crest vertical curve, a sag vertical curve, or an angle point at which two different roadway grades meet
- Beginning or end of a passing lane or short four-lane section provided for the purpose of increasing passing opportunities
- Beginning or end of a center two-way left-turn lane

Each intersection is treated as a separate analysis unit. After this segmentation process, the roadway to be evaluated will consist of roadway segments of varying length, each of which is homogeneous with respect to traffic volume, lane width, shoulder width and type, driveway density, roadside hazard rating, curvature, grade, presence of passing lanes or short four-lane sections, and presence of center two-way left-turn lanes. It should be noted that for purposes of this chapter, spiral transitions are considered part of the tangent they adjoin and vertical curves are considered part of the grades they adjoin (i.e., grades run from PVI to PVI with no explicit consideration of any vertical curve that may be present).

EXHIBIT 11. FLOW DIAGRAM OF THE SAFETY PREDICTION METHODOLOGY WHEN NO SITE-SPECIFIC ACCIDENT HISTORY DATA ARE AVAILABLE.

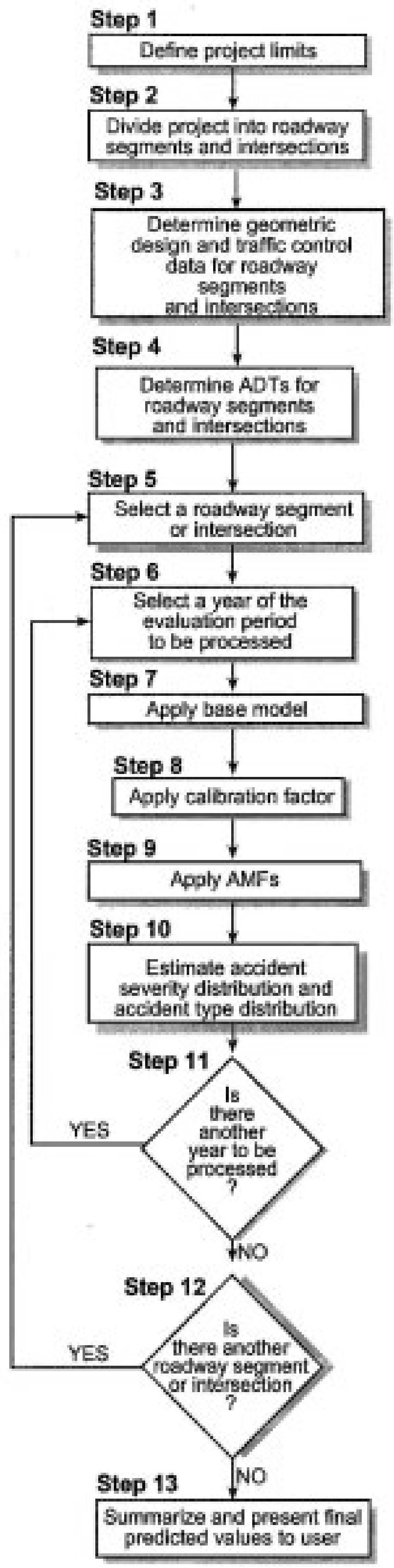


Exhibit 11 presents a flow diagram for the procedure used when no site-specific accident history data are available.

Roadway Segments

The steps required to determine expected accident frequency for each roadway segment is presented below:

Steps 3a through 12a deal with roadway segments.

Step 3a—Determine the geometric design and traffic control features for a particular roadway segment.

For each roadway segment, the following geometric and traffic control features must be quantified:

The list shown here presents the geometric and traffic control data needed for roadway segments.

- Length of segment (mi)
- ADT (veh/day)
- Lane width (ft)
- Shoulder width (ft)
- Shoulder type (paved/gravel/composite/turf)
- Presence or absence of horizontal curve (curve/tangent)
- Length of horizontal curve (mi), if the segment is located on a curve (This represents the total length of the horizontal curve, even if the curve extends beyond the limits of the roadway segment being analyzed.)
- Radius of horizontal curve (ft), if the segment is located on a curve
- Presence or absence of spiral transition curve, if the segment is located on a curve (This represents the presence or absence of a spiral transition curve at the beginning and end of the horizontal curve, even if the beginning and/or end of the horizontal curve are beyond the limits of the segment being analyzed.)
- Superelevation of horizontal curve, if the segment is located on a horizontal curve
- Grade (percent), considering each grade as a straight grade from PVI to PVI (i.e., ignoring the presence of vertical curves)
- Driveway density (driveways per mi)
- Presence or absence of a passing lane to increase passing opportunities
- Presence or absence of a short four-lane Section to increase passing opportunities
- Presence or absence of a two-way left-turn lane
- Roadside hazard rating

Step 4a—Determine the ADTs for each roadway segment and intersection during each year for which the expected safety performance is to be predicted.

For each roadway segment, ADT data are needed for each year of the period to be evaluated. If these values are not accessible, the following default rules should be applied within the safety prediction methodology to estimate the ADTs for years for which the data are not available. If ADT data are available for only a single year, that same value is assumed to apply to all years of the analysis period. If two or more years of ADT data are available, the ADTs for intervening years are computed by interpolation. ADTs for years before the first year for which data are available are assumed to be equal to the ADT for that first year; ADTs for years after the last year for which data are available are assumed to be equal to the last year.

Step 5a—Select an individual roadway segment for evaluation. If there are no more roadway segments to be evaluated, go to Step 13.

Roadway segments are evaluated one at a time. Steps 6a through 11a, described below, are repeated for each roadway segment.

Step 6a—Select a particular year of the specified evaluation period for the roadway segment. If there are no more years to be evaluated for that roadway segment, go to Step 12a.

The individual years of the evaluation period are evaluated one year at a time for any particular roadway segment. Separate estimates are made for each year because several of the AMFs considered in Step 9a are dependent on the ADT of the roadway segment, which may change from year to year. Steps 7a through 10a, described below, are repeated for each year of the evaluation period as part of the evaluation of any particular roadway segment.

Step 7a—Apply the appropriate base model to determine the predicted accident frequency for nominal or base conditions for the selected year.

The predicted accident frequency for nominal or base conditions is determined with Equation (4). The ADT(s) used in the base model should be the ADT(s) for the selected year of the evaluation period.

Step 8a—Multiply the result obtained in Step 7a by the appropriate calibration factor.

The calibration factor used in Step 8a is the calibration factor for roadway segments (C_r) discussed in Appendix A.

Step 9a—Multiply the result obtained in Step 8a by the appropriate AMFs representing safety differences between the nominal or base conditions and the actual geometrics and traffic control of the roadway segment.

The AMFs for roadway segments are those presented in Equations (6) through (16). Steps 7a, 8a, and 9a together implement Equation (1).

Step 10a—Estimate the expected distribution of accident severities and accident types for the particular roadway segment from the default distributions of accident severity and accident type.

The predictions of accident frequencies are supplemented by breaking down those frequencies by accident severity and by accident type. This provides greater insight about safety conditions within the project. The accident severity and accident type estimates are based on the default distributions of accident severity and accident type presented in Exhibits 2 and 3, respectively. These default distributions may be changed as part of the calibration process.

Step 11a—If there is another year to be evaluated for the selected roadway segment, return to Step 6a. Otherwise, proceed to Step 12a.

This step creates a loop through Steps 7a to 10a that is repeated for each year of the evaluation period for the particular roadway segment.

Step 12a—If there is another roadway segment to be evaluated, return to Step 5a, otherwise, proceed to Step 13.

This step creates a loop through Step 6a to 11a that is repeated for each roadway segment within the project.

A worksheet for computing the predicted accident frequency for a particular roadway segment during a particular year is shown in Exhibit 12.

Steps 3b through 12b deal with intersections.

The list shown here presents the geometric and traffic control data needed for intersections.

At-Grade Intersections

Steps 3b through 12b are similar to the roadway segment Steps 3a through 12a, but are adapted for at-grade intersection calculations.

Step 3b—Determine the geometric design and traffic control features for a particular intersection.

For each intersection, the following geometric and traffic control features must be quantified:

- Number of intersection legs (3 or 4)
- Type of traffic control (minor-road STOP, all-way STOP, minor-road YIELD control, or signal)
- Intersection skew angle (degrees departure from 90 degrees, with a + or – sign indicating the direction of the departure)
- Number of major-road approaches with intersection left-turn lanes (0, 1, or 2)
- Number of major-road approaches with intersection right-turn lanes (0, 1, or 2)
- Number of intersection quadrants with deficient intersection sight distance (0, 1, 2, 3, or 4)

Step 4b—Determine the ADTs for each intersection during each year for which the expected safety performance is to be predicted.

For each major- and minor-road approaches to each intersection, ADT data are needed for each year of the period to be evaluated. If ADTs are available for every roadway segment, the major-road ADTs for intersection approaches can be determined without additional data. If the ADTs on the two major-road legs of an intersection differ, the average of the two ADT values should be used for the intersection. For a three-leg intersection, the user should enter the ADT of the minor-road leg. For a four-leg intersection, the user should enter the average of the ADTs for the two minor-road legs.

In many cases, it is expected that ADT data will not be available for all years of the evaluation period. In that case, the analyst should interpolate or extrapolate as appropriate to obtain an estimate of ADT for each year of the evaluation period. If the analyst does not have established procedures for doing this, the following default rules should be applied within the safety prediction methodology to estimate the ADTs for years, for which the data are not available. If ADT data are available for only a single year, that same value is assumed to apply to all years of the analysis period. If two or more years of ADT data are available, the ADTs for intervening years are computed by interpolation. ADTs for years before the first year for which data are available are assumed to be equal to the ADT for that first year; ADTs for years after the last year for which data are available are assumed to be equal to the last year.

Step 5b—Select an individual intersection for evaluation. If there are no more intersections to be valuated, go to Step 13.

Intersections are evaluated one at a time. Steps 6b through 11b, described below, are repeated for each intersection.

Step 6b—Select a particular year of the specified evaluation period for the particular intersection. If there are no more years to be evaluated for the intersection, go to Step 12b.

The individual years of the evaluation period are evaluated one year at a time for any particular intersection. Separate estimates are made for each year because several of the AMFs considered in Step 9b are dependent on the ADT of the intersection, which

Exhibit 12 presents the safety prediction worksheet for roadway segments.

EXHIBIT 12. SAFETY PREDICTION WORKSHEET FOR A ROADWAY SEGMENT

ROADWAY SEGMENT SAFETY PREDICTION WORKSHEET	
General Information	***Site Information***
Analyst ____ Agency or Company ____ Date Performed ____ Analysis Time Period ____	Highway ____ Roadway Section ____ Jurisdiction ____ Analysis Year ____
Input Data	
Length of segment (mi) – L	
ADT (veh/day)	
Lane width (ft)	
Shoulder width (ft)	
Shoulder type (paved/gravel/composite/turf)	
Presence or absence of horizontal curve (curve/tangent)	
Length of horizontal curve	
Radius of horizontal curve (ft)	
Presence or absence of spiral transition curve	
Superelevation of horizontal curve	
Grade (percent), straight grade from PVI to PVI	
Driveway density (driveway per mi)	
Presence or absence of passing lane	
Presence or absence of a short four-lane section	
Presence or absence of a two-way left-turn lane	
Roadside hazard rating	
Base Model	
From Equation (5): $N_{br} = (ADT)(L)(365)(10^{-6})\exp(-0.4865)$	
Accident Modification Factors	
Lane width (if lane widths differ for two directions, determine the AMFs separately)	
AMF_{ra} - AMF for Related Accident (Exhibit 4)	
AMF = $(AMF_{ra} - 1)0.35+1.0$	
Shoulder width and type AMF (if widths and or type differ for two directions, determine the AMFs separately)	
AMF_{wra} - AMF for related accidents based on shoulder width (Exhibit 5) AMF_{tra} - AMF for related accidents based on shoulder type (Exhibit 6)	
AMF = $(AMF_{wra}\ AMF_{tra} - 1.0)\ 0.35 + 1.0$	
Horizontal Curve	
Length, Radius and Presence or Absence of Spiral Transition	
$AMF_{LRS} = \dfrac{1.55L_c + \dfrac{80.2}{R} - 0.012S}{1.55L_c}$ (Equation [8])	
Superelevation	
SD - Super elevation (Exhibit 7)	
If SD < 0.01, $AMF_S = 1.00$ If $0.01 \le SD < 0.02$, $AMF_S = 1.00 + 6(SD-0.01)$ If $SD \ge 0.02$, $AMF_S = 1.6 + 3\ (SD-0.02)$	
AMF = $AMF_{LRS}\ .\ AMF_S$	
Grades	
AMF (Exhibit 9)	
Driveway Density	
$AMF = \dfrac{0.2+[0.05-0.05\ln(ADT)]DD}{0.2+[0.05-0.05\ln(ADT)](5)}$ (Equation [13])	
Passing Lanes	
For conventional passing lane added in one direction of travel on the two-lane highway - AMF = 0.75 For short four-lane sections - AMF = 0.65	
Two-Way Left-Turn Lanes	
$P_D = \dfrac{0.0047DD + 0.0024DD^2}{1.199 + 0.0047DD + 0.0024DD^2}$ (Equation [15]) $P_{LT/D} = 0.5$	
AMF = $1\text{-}0.7\ P_D\ P_{LT/D}$ (Equation [14])	
Roadside Design	
Determine appropriate roadside hazard rating RHR from Appendix C	
$AMF = \dfrac{\exp(-0.6869 + 0.0668RHR)}{\exp(-0.4865)}$ (Equation [16])	
Calibration Factor	
C_r (Appendix A)	
Safety Prediction Model	
From Equation (1): $N_{rs} = N_{br}\, C_r\, (AMF_{1r}\ AMF_{2r} \ldots AMF_{nr})$	

may change from year to year. Steps 7b through 10b, described below, are repeated for each year of the evaluation period as part of the evaluation of any particular intersection.

Step 7b—Apply the appropriate base model to determine the predicted accident frequency for nominal or base conditions for the selected year.

The predicted accident frequency for nominal or base conditions is determined with one of the following base models:

- Three-leg STOP-controlled intersections Equation (18)
- Four-leg STOP-controlled intersections Equation (20)
- Four-leg signalized intersections Equation (22)

The ADT(s) used in the base model should be the ADT(s) for the selected year of the evaluation period.

Step 8b—Multiply the result obtained in Step 7b by the appropriate calibration factor.

The calibration factors used in Step 8b are the calibration for intersections (C_i) discussed in Appendix A.

Step 9b—Multiply the result obtained in Step 8b by the appropriate AMFs representing safety differences between the nominal or base conditions and the actual geometrics and traffic control of the intersection.

The AMFs for intersections are those described in "Accident Modification Factors for At-Grade Intersections" section. Steps 7b, 8b, and 9b together implement Equation (2).

Step 10b—Estimate the expected distribution of accident severities and accident types for the particular intersection of interest from the default distributions of accident severity and accident type.

The predictions of accident frequencies are supplemented by breaking down those frequencies by accident severity and by accident type. The accident severity and accident type estimates are based on the default distributions of accident severity and accident type presented in Exhibits 2 and 3, respectively. These default distributions may be changed as part of the calibration process.

Step 11b—If there is another year to be evaluated for the selected intersection, return to Step 6b. Otherwise, proceed to Step 12b.

This step creates a loop through Steps 7b to 10b that is repeated for each year of the evaluation period for a particular intersection.

Step 12b—If there is another intersection to be evaluated, return to Step 5b, otherwise, proceed to Step 13.

This step creates a loop through Steps 6b to 11b that is repeated for each intersection within the project.

A worksheet for computing the predicted accident frequency for a particular intersection during a particular year is shown in Exhibit 13.

Combine Results for Entire Project

Step 13—Summarize and present the accident predictions.

The total predicted accident frequency for an entire project or an extended highway section can be determined by summing the accidents predicted for all roadway segments and intersections comprised by the project. The worksheet for safety prediction computations for an entire project is shown in Exhibit 14.

Exhibit 13 presents the safety prediction worksheet for intersections.

EXHIBIT 13. SAFETY PREDICTION WORKSHEET FOR AN AT-GRADE INTERSECTION

AT-GRADE INTERSECTION SAFETY PREDICTION WORKSHEET	
General Information	***Site Information***
Analyst ________________ Agency or Company ________________ Date Performed ________________ Analysis Time Period ________________	Highway ________________ Intersection ________________ Jurisdiction ________________ Analysis Year ________________
Input Data	
Number of intersection legs (3 or 4)	
Type of traffic control (minor-road, al-way STOP, minor-road YIELD control, or signal)	
Intersection skew angle (degrees departure from 90 degrees)	
Number of major-road approaches with intersection left-turn lanes (0, 1, or 2)	
Number of major-road approaches with intersection right-turn lanes (0, 1, or 2)	
Number of intersection quadrants with deficient intersection sight distance (0, 1, 2, 3, or 4)	
ADT for major road during analysis year	
ADT for minor road during analysis year	
Base Model	
Three-leg STOP-controlled intersection—Equation (18)	
Four-leg STOP-controlled intersection—Equation (20)	
Four-leg signalized intersections—Equation (22)	
Accident Modification Factors	
Left-turn Lane AMF for total intersection-related left-turn lanes (see Exhibit 10)	
Right-turn Lane The AMFs for right-turn lanes at intersection are: Stop-controlled 0.95 RTL on one major-road approach 0.90 RTLs on both major-road approaches Signalized 0.975 RTL on one major-road approach 0.95 RTLs on both major-road approaches	
Intersection Sight Distance The AMFs for intersection sight distance at intersection with STOP or Yield control on the minor leg(s) are: 1.05-sight distance limited in one quadrant 1.10-sight distance limited in two quadrants 1.15-sight distance limited in three quadrants 1.20-sight distance limited in four quadrants An AMF of 1.00 is applicable to signal-controlled and all way STOP-controlled intersections	
Calibration Factor	
C_i (Appendix A)	
Safety Prediction Model	
From Equation (2): $N_{int} = N_{bi}\, Ci\, (AMF_{1i}\, AMF_{2i} \ldots AMF_{ni})$	

Exhibit 14 presents the worksheet used to combine safety estimates for all roadway segments and intersections within a given project.

EXHIBIT 14. SAFETY PREDICTION WORKSHEET FOR AN ENTIRE PROJECT

ENTIRE PROJECT SAFETY PREDICTION WORKSHEET	
General Information	***Site Information***
Analyst ________________ Agency or Company ________________ Date Performed ________________ Analysis Time Period ________________	Highway ________________ Roadway Section ________________ Jurisdiction ________________ Analysis Year ________________
Input Data	
Sum of accident prediction values for all roadway segments that comprise the project (get results from Exhibit 12 for each roadway segment and each analysis year) - ΣN_{rs}	
Sum of accident prediction values for all at-grade intersections that comprise the project (get results from Exhibit 13 for each intersection and each analysis year) - ΣN_{int}	
Safety Prediction Model for an Entire Project	
N_t using Equation (3), sum the accident prediction values of all roadway segments and intersections that comprise the project: $N_t = \Sigma N_{rs} + \Sigma N_{int}$	

The second application deals with safety prediction when site-specific accident history data are available.

SAFETY PREDICTION WHEN SITE-SPECIFIC ACCIDENT HISTORY DATA ARE AVAILABLE

Consideration of site-specific accident history data in the safety prediction methodology increases the accuracy of the predicted accident frequencies. When at least two years of site-specific accident history data are available for the project being evaluated, and when the project meets certain criteria discussed below, the accident history data should be used. When considering site-specific accident history data, the procedure must consider both the existing geometric design and traffic control for the project (i.e., the conditions that existed during the *before* period while the accident history was accumulated) and the proposed geometric design and traffic control for the project (i.e., the conditions that will exist during the *after* period, the period for which accident predictions are being made). The Empirical Bayes (EB) procedure discussed below provides a method to combine predictions from the procedure with site-specific accident history data.

Situations in Which the EB Procedure Should and Should Not be Applied

The applicability of the EB procedure depends on the availability of observed accident history data and the type of improvement project being evaluated. If no observed accident history data are available, application of the EB procedure is infeasible and should not be considered. If observed accident history data are available, the applicability of the EB procedure depends on the type of improvement project being evaluated.

The EB procedure should be applied for the following improvement types whenever at least two years of the observed accident history data are available:

The EB procedure should be applied for these improvement types.

- Sites at which the roadway geometrics and traffic control are not being changed (e.g., the "do-nothing" alternative)
- Projects in which the roadway cross section is modified but the basic number of lanes remains the same (This would include, for example, projects for which lanes or shoulders were widened or the roadside was improved, but the roadway remained a rural two-lane highway)
- Projects in which minor changes in alignment are made, such as flattening individual horizontal curves while leaving most of the alignment intact
- Projects in which a passing lane or a short four-lane section is added to a rural two-lane highway to increase passing opportunities
- Any combination of the above improvements

The EB procedure is not applicable to the following types of improvements:

The EB procedure should not be applied for these improvement types.

- Projects in which a new alignment is developed for at least 50 percent of the project length. In this case, the procedure used when no site-specific accident history data are available should be applied because there is no reason why the accident history of the old alignment should be used as a predictor of future accident frequency on the new alignment. For cases in which the user is concerned that a particular geographic area or corridor has higher or lower accident experience than expected, a special study may be performed to develop a local calibration factor (see Appendix A).
- Individual intersections at which the basic number of intersection legs or type of traffic control is changed as part of a project. The EB procedure can be applied to the rest of any project containing such an intersection, but the intersection itself should be omitted.

The reason that the EB procedure is not used for these project types is that the observed accident data for a previous time period is not necessarily indicative of the accident experience that is likely to occur in the future, after such a major geometric improvement.

Accident Data Location Specifications

Accident data could be specified either by specific locations (a single station for each accident occurrence) or by location ranges (two stations as a station range for each crash occurrence). Accidents should be attributed either to roadway homogenous segments or to intersections. Intersection-related accidents within 76 m (250 ft) of the center of the intersection should be attributed to that intersection. If the centers of two intersections are closer than 500 feet, the accidents between the two intersections should be assigned to the closest intersection. Non-intersection-related accidents and intersection-related accidents located more than 76 m (250 ft) from the center of an intersection should be attributed to the roadway homogenous segments within which the accident falls. The available accident data should be used to determine both total observed accidents and accidents by severity level.

Accident data could be specified either by specific locations or by location ranges.

Empirical Bayes Procedure

The EB procedure has three major steps as follows:

EB-Step1: Computing the expected accident frequency for before period (E_p)
EB-Step2: Matching the before and after periods roadways
EB-Step3: Obtaining an estimate of expected accident frequency for after period

The EB procedure has three major steps, computing (Ep), matching the before and after period roadways and obtaining an estimate of expected accident frequency for after period.

From the above steps only the first step, EB-Step1, would be affected by the way the accident locations are specified. The second and the third steps would not be affected by this. When the historical accident data are stored by specific stations, the algorithm must assign each accident to a road homogenous segment or intersection. When the historical accident data are stored by station ranges (i.e., accident segments), first the expected accident frequency for before period for the accident segments should be calculated. Then the homogenous segments should be mapped into the accident segments. Finally, the expected accident frequency for before period for the homogenous segments should be calculated. These steps are described in the following sections.

EB-Step1, Computing the expected accident frequency for before period (Ep)

Computing the expected accident frequency for each homogenous segment for before period (Ep) is based on a weighted average of the "Model" prediction and the "Observed" number of accidents.

EB-Step1 for Accidents Specified by Locations

If accidents are specified by locations, the EB procedure provides a method to combine the accident frequencies predicted by the safety prediction procedure (N_p) with the accident frequency from the site-specific accident history data (N_o). The EB procedure uses a weighted average of N_p and N_o.

The expected accident frequency considering both the predicted and observed accident frequencies for "before period" is computed as:

Equation (29) is used to combine predicted and observed accident frequencies in the EB procedure.

$$E_p = w(N_p) + (1 - w)N_o \quad (29)$$

where:

E_p = expected total accident frequency for before period based on a weighted average of N_p and N_o;

N_p = number of accidents predicted by the safety prediction methodology during a specified period of time (equal to N_{rs} for a roadway segment or N_{int} for an intersection);

Equation (30) is used to determine the weight, w, needed for Equation (29).

Exhibit (15) presents the overdispersion parameter, k, needed for Equation (30).

w = weight to be placed on the accident frequency predicted by the safety prediction methodology; and
O = number of accidents observed during a specified period of time.

The weight placed on the predicted accident frequency is determined in the EB procedure as:

$$w = \frac{1}{1 + k(N_p/LL)} \tag{30}$$

where:
k = overdispersion parameter of the relevant base model from the safety prediction methodology.
LL = length of analysis section (for a roadway segment, LL = L; for an intersection, LL = 1).

Equation (30) shows an inverse relationship between the magnitude of the predicted accident frequency predicted by the procedure, N_p, and the weight, w. Therefore, as the predicted value of N_p increases, the weight placed on N_p decreases. This relationship implies that the higher the predicted accident frequency for a particular location, the more the reliance that should be placed on the observed site-specific accident history and the less the reliance that should be placed on the model prediction itself. By contrast, when the model prediction is smaller, less reliance should be placed on the observed site-specific accident history and greater reliance should be placed on the model prediction.

Exhibit 15 shows the values of the overdispersion parameters (k) for the four base models used in the safety prediction procedure.

EXHIBIT 15. OVERDISPERSION PARAMETERS FOR BASE MODELS AND MINIMUM ACCIDENT FREQUENCIES FOR EB PROCEDURE.

Geometric element	Overdispersion parameter for base model (k)
Roadway segment	0.24
Three-leg STOP-controlled intersection	0.54
Four-leg STOP-controlled intersection	0.24
Four-leg signalized intersection	0.11

A computation analogous to Equation (29) should also be performed separately by accident severity level for fatal and injury accidents and for property damage only accidents using the following equations:

$$E_{fi} = W(N_{p(fi)}) + (1-w)\,N_{o(fi)} \tag{31}$$

$$E_{pdo} = W(N_{p(pdo)}) + (1-w)\,N_{o(pdo)} \tag{32}$$

where:

- E_{fi} = expected accident frequency for fatal and injury accidents
- E_{pdo} = expected accident frequency for property damage only accidents
- $N_{p(fi)}$ = number of fatal and injury accidents predicted by the safety prediction methodology for a specified period of time (i.e., N_p times the appropriate proportion of fatal and injury accidents from Exhibit 2)
- $N_{p(pdo)}$ = number of property damage only accidents predicted by the safety prediction methodology for a specified period of time (i.e., N_p times the appropriate proportion of property damage only accidents from Exhibit 2)
- $N_{o(fi)}$ = number of fatal and injury accidents observed during a specified period of time
- $N_{o(fi)}$ = number of property damage only accidents observed during a specified period of time

Because E_{fi} and E_{pdo} are estimated independently, their sum may not equal E_p. Therefore, a correction should be made as follows:

$$E_{fi/corr} = E_p \left(\frac{E_{fi}}{E_{fi} + E_{pdo}} \right) \tag{33}$$

$$E_{pdo/corr} = E_p \left(\frac{E_{pdo}}{E_{fi} + E_{pdo}} \right) \tag{34}$$

where:

- $E_{fi/corr}$ = expected accident frequency for fatal and injury accidents (corrected)
- $E_{pdo/corr}$ = expected accident frequency for property-damage-only accidents (corrected)

The sum of the corrected values $E_{fi/corr}$ and $E_{pdo/corr}$ would be equal to E_p:

$$E_p = E_{fi/corr} + E_{pdo/corr} \tag{35}$$

EB-Step1 for Accidents Specified by Location Ranges

If the accidents are specified by location ranges, the following procedure is followed to compute the expected accident frequency considering both the predicted and observed accident frequencies for "before period." There is the assumption associated with an accident location range that the accident occurrence rate along this range is constant. The first six steps of the following procedure should be followed for the total number of accidents as well as for fatal and injury accidents and for property damage only accidents.

1. Build up a new segmentation on the before period roadway named "Accident Segmentation." This segmentation is based on the mapping of all accidents on their associated ranges on the before period roadway and building segments on which the total accident occurrence rate is constant.

   As an example if there is a 4-mile roadway with accident data recorded as 2 accidents between stations zero and two, and 3 accidents between stations one and three, the accident segments would be from station zero to station one, from station one to station two, from station two to station three, and from station three to station four with accident occurrence rates of 1, 2.5, 1.5 and 0 respectively.

2. Calculate the predicted accident rates for all roadway homogenous segments located within each accident segment.
3. Determine the predicted number of accidents for all portions of the roadway homogenous segments located within each accident segment.
4. Calculate the total predicted number of accidents on each accident segment by summing the contributions of each portion of the roadway homogenous segment located within that accident segment.
5. Calculate a predicted accident rate for each accident segment by taking the predictions from Step 4 and dividing by the length of the accident segment.
6. Determine the expected accident frequency for each accident segment by using Equations 30, 29, 31, and 32.
7. Adjust the expected accident frequency for each accident segment using equations 33 and 34.
8. Calculate the proportion of accidents expected to occur on each accident segment for each roadway homogenous segment located within that accident segment.
9. Determine the expected accident frequency for each roadway homogenous segment E_p by summing the contributions of that segment located within all corresponding accident segments.

EB-Step2, Matching the before and after periods roadways

Matching the before and after periods roadway homogenous segments is necessary especially when the length of any segment of the roadway is changed. The most common source for such a change is change in curve radius. If we flatten a horizontal curve, the length of the roadway as well as the homogenous segmentation on the flattened curve and adjacent design elements would change. In this step if necessary extra segmentation should be established for both roadways. Each homogenous segment of the before period roadway is matched to a homogenous segment of the after period roadway. This process is described in detail in Appendix C.

EB-Step3, Obtaining an estimate of expected accident frequency for after period

The value of E_p represents the expected accident frequency for a given roadway segment or intersection during the before period. To obtain an estimate of expected accident frequency in a future period (the *after* period), the estimate must be corrected for (1) any difference in the duration of the before-and-after periods; (2) any growth or decline in ADTs between the before-and-after periods; and (3) any changes in geometric design or traffic control features between the before-and-after periods that affect the values of the AMFs for the roadway segment or intersection. The expected accident frequency for a roadway segment or intersection in the after period can be estimated as:

$$E_f = E_p\,(N_{bf} / N_{bp})\,(AMF_{1f} / AMF_{1p})\,(AMF_{2f} / AMF_{2p})\ldots(AMF_{nf} / AMF_{np}) \quad (36)$$

where:

E_f = expected accident frequency during the future time period for which accidents are being forecast for the analysis segment or intersection in question;

E_p = expected accident frequency for the past time period for which accident history data were available;

N_{bf} = number of accidents forecast by the base model using the future ADT data, the specified nominal values for geometric parameters, and—in the case of an analysis segment—the actual length of the analysis segment;

N_{bp} = number of accidents forecast by the base model using the past ADT data, the specified nominal values for geometric parameters, and—in the case of an analysis segment—the actual length of the analysis segment;

AMF_{xf} = value of the x^{th} AMF for the geometric conditions planned for the future (i.e., proposed) design; and

AMF_{xp} = value of the x^{th} AMF for the geometric conditions for the past (i.e., existing) design.

Because of the form of the base model for roadway segments, if the length of the homogenous segments are not changed the ratio N_{bf} / N_{bp} is the same as the ratio of the traffic volumes, ADT_f / ADT_p. However, for intersections, the ratio N_{bf} / N_{bp} must be evaluated explicitly with the base models because the intersection base models incorporate separate major- and minor-road ADT terms with differing coefficients. In applying Equation (36), the values of N_{bp}, N_{bf}, AMF_{xp}, and AMF_{xf} should be based on the average ADTs during the entire before or after period, respectively.

Equation (36) is applied to total accident frequency. The expected future accident frequencies by severity level should also be determined by multiplying the expected accident frequency from the before period for each severity level by the ratio E_f / E_p.

In the case of minor changes in roadway alignment (i.e., flattening a horizontal curve), the length of an analysis segment may change from the past to the future time period. If any segment length were changed, the matching process explained in Appendix C would create extra segmentation by which the two alignments would match segment by segment with no problem. Of course, the AMF ratios that also appear in Equation (B-12) will account for any change in geometrics (i.e., reduction in radius of curvature) that accompany a change in length.

IV. EXAMPLE PROBLEMS

In this section, six representative example problems are solved using the computation steps and worksheets presented in Applications section. Examples 1 and 2 illustrate how to calculate the accident frequency per year for two cases of two-lane roadway segment. Example 1 addresses a tangent segment and Example 2 addresses a horizontal curve. Examples 3 and 4 illustrate how to estimate the accident frequencies for a three-leg stop-controlled intersection and a four-leg signalized intersection. Examples 5 and 6 illustrates how to estimate the accident frequency for an entire project that, in this case, is comprised of the two roadway segments and two intersections addressed in Examples 1 through 4. Example 5 addresses the case when no site-specific accident history data are available. Example 6 addresses the application of the EB methodology when site-specific accident history data are available.

Problem No.	Description
1	Predict the number of accidents for a tangent roadway segment
2	Predict the number of accidents for a curved roadway segment
3	Predict the number of accidents for a four-leg signalized intersection
4	Predict the number of accidents for a three-leg stop-controlled intersection
5	Predict the number of accidents for an entire project for which no site-specific accident history data available
6	Predict the number of accidents for an entire project for which site-specific accident history data available

EXAMPLE PROBLEM 1

Example Problem 1 addresses a two-lane tangent roadway segment.

The Highway Two-lane tangent roadway segment

The Question What is the predicted accident frequency of the roadway segment for a particular year?

The Facts

- ✓ 1.5-mi length
- ✓ 5000 veh/day
- ✓ 10-ft lane width
- ✓ 4-ft gravel shoulder
- ✓ Tangent roadway segment
- ✓ 2% grade
- ✓ 6 driveways per mi
- ✓ Roadside hazard rating = 4
- ✓ Calibration factor = 1.10

Outline of Solution Base model, accident modification factors, and calibration factors will be calculated for the roadway segment, and from these parameters the accident prediction model will be used to calculated the accident frequency.

Steps Presented in the roadway segment accident prediction worksheet (Exhibit 16)

Results The predicted accident frequency for two-lane roadway segment is 2.9 accidents per year

EXHIBIT 16. EXAMPLE PROBLEM 1—TANGENT ROADWAY SEGMENT

ROADWAY SEGMENT ACCIDENT PREDICTION WORKSHEET	
General Information	***Site Information***
Analyst: Mary Smith Agency or Company: State DOT Date Performed: 02/03/02 Analysis Time Period: ____________	Highway: US71 Roadway Section: ____________ Jurisdiction: ____________ Analysis Year: 2002
Input Data	
Length of segment (mi) - L	1.5
ADT (veh/day)	5000
Lane width (ft)	10
Shoulder width (ft)	4
Shoulder type (paved/gravel/composite/turf)	gravel
Presence or absence of horizontal curve (curve/tangent)	tangent
Length of horizontal curve (mi)	–
Radius of horizontal curve (ft)	–
Presence or absence of spiral transition curve	–
Superelevation of horizontal curve	–
Grade (percent), straight grade from PVI to PVI	2%
Driveway density (driveway per mi)	6
Presence or absence of passing lane	none present
Presence or absence of a short four-lane Section	none present
Presence or absence of a two-way left-turn lane	none present
Roadside hazard rating	4
Base Model	
From Equation (5): N_{br} = (ADT)(L)(365)(10^{-6})exp (-0.4865)	1.683
Accident Modification Factors	
Lane width AMF(if lane widths differ for two directions, determine the AMFs separately)	
AMF_{ra} - AMF for Related Accident (Exhibit 4)	1.30
AMF = (AMF_{ra} - 1)0.35+1.0	1.105
Shoulder width and type AMF (if widths and or type differ for two directions, determine the AMFs separately)	
AMF_{wra} - AMF for related accidents based on shoulder width (Exhibit 5) AMF_{tra} - AMF for related accidents based on shoulder type (Exhibit 6)	1.15 1.01
AMF = (AMF_{wra} AMF_{tra} - 1.0) 0.35 + 1.0	1.057
Horizontal Curve	
Length, Radius and Presence or Absence of Spiral Transition	
$AMF_{LRS} = \dfrac{1.55L_C + \dfrac{80.2}{R} - 0.012S}{1.55L_C}$ (Equation [8])	–
Superelevation	
SD - Superelevation Deficiency (Exhibit 7)	–
If SD < 0.01, AMF_S = 1.00 If 0.01 ≤ SD < 0.02, AMF_S = 1.00 + 6(SD-0.01) If SD ≥ 0.02, AMF_S = 1.6 + 3 (SD-0.02)	–
AMF = AMF_{LRS} . AMF_S	1.0
Grades	
AMF (Exhibit 9)	1.03
Driveway Density	
$AMF = \dfrac{0.2+[0.05-0.05\ln(ADT)]DD}{0.2+[0.05-0.05\ln(ADT)](5)}$ (Equation [13])	1.224
Passing Lanes	
For conventional passing lane added in one direction of travel on the two-lane highway - AMF = 0.75 For short four-lane sections - AMF = 0.65	1.0
Two-Way Left-Turn Lanes	
$P_D = \dfrac{0.0047DD + 0.0024DD^2}{1.199 + 0.0047DD + 0.0024DD^2}$ (Equation [15]) $P_{LT/D}$ = 0.5	–
AMF = 1-0.7 P_D $P_{LT/D}$ (Equation [14])	1.0
Roadside Design	
Determine appropriate roadside hazard rating RHR from Appendix C	4
$AMF = \dfrac{\exp(-0.6869 + 0.0668RHR)}{\exp(-0.4865)}$ (Equation [16])	1.069
Calibration Factor	
C_r (Appendix A)	1.10
Accident Prediction Model	
From Equation (1): N_{rs} = N_{br} C_r (AMF_{1r} AMF_{2r} … AMF_{nr})	2.9

Exhibit 16 presents the completed accident prediction worksheet for Example Problem 1.

Example Problem 2 addresses a two-lane curved roadway segment.

EXAMPLE PROBLEM 2

The Highway Two-lane curved roadway segment

The Question What is the predicted accident frequency of the roadway segment for a particular year?

The Facts

- ✓ 0.1-mi length
- ✓ 3000 veh/day
- ✓ 11-ft lane width
- ✓ 2-ft gravel shoulder
- ✓ 1% grade
- ✓ No driveways
- ✓ Curve roadway segment
- ✓ 1200-ft horizontal curve radius
- ✓ No spiral transition
- ✓ Horizontal curve length = 0.1 mile
- ✓ Superelevation = 0.4
- ✓ Roadside hazard rating = 5
- ✓ Calibration factor = 1.10

Outline of Solution Base model, accident modification factors, and calibration factors will be calculated for the horizontal curve, and from these parameters the accident prediction model will be used to calculated the accident frequency.

Steps Presented in the roadway segment accident prediction worksheet (Exhibit 17)

Results The predicted accident frequency for two-lane roadway segment is 0.14 accidents per year

EXHIBIT 17. EXAMPLE PROBLEM 2—HORIZONTAL CURVE

ROADWAY SEGMENT ACCIDENT PREDICTION WORKSHEET	
General Information	***Site Information***
Analyst: Mary Smith Agency or Company: State DOT Date Performed: 02/07/02 Analysis Time Period: ________	Highway: US 71 Roadway Section: ________ Jurisdiction: ________ Analysis Year: 2002
Input Data	
Length of segment (mi) - L	0.1
ADT (veh/day)	3000
Lane width (ft)	11
Shoulder width (ft)	2
Shoulder type (paved/gravel/composite/turf)	turf
Presence or absence of horizontal curve (curve/tangent)	curve
Length of horizontal curve (mi)	0.1
Radius of horizontal curve (ft)	1200
Presence or absence of spiral transition curve	absence
Superelevation of horizontal curve	0.4
Grade (percent), straight grade from PVI to PVI	1%
Driveway density (driveway per mi)	0
Presence or absence of passing lane	none present
Presence or absence of a short four-lane Section	none present
Presence or absence of a two-way left-turn lane	none present
Roadside hazard rating	5
Base Model	
From Equation (5): N_{br} = (ADT)(L)(365)(10^{-6})exp (–0.4865)	0.067
Accident Modification Factors	
Lane width AMF(if lane widths differ for two directions, determine the AMFs separately)	
AMF_{ra} - AMF for Related Accident (Exhibit 4)	1.05
AMF = (AMF_{ra} - 1)0.35+1.0	1.018
Shoulder width and type AMF (if widths and or type differ for two directions, determine the AMFs separately)	
AMF_{wra} - AMF for related accidents based on shoulder width (Exhibit 5) AMF_{tra} - AMF for related accidents based on shoulder type (Exhibit 6)	1.30 1.03
AMF = (AMF_{wra} AMF_{tra} - 1.0) 0.35 + 1.0	1.119
Horizontal Curve	
Length, Radius and Presence or Absence of Spiral Transition	
$AMF_{LRS} = \frac{1.55L_C + \frac{80.2}{R} - 0.012S}{1.55L_C}$ (Equation [8])	1.43
Superelevation	
SD - Superelevation Deficiency (Exhibit 7)	0
If SD < 0.01, AMF_S = 1.00 If 0.01 ≤ SD < 0.02, AMF_S = 1.00 + 6(SD-0.01) If SD ≥ 0.02, AMF_S = 1.6 + 3 (SD-0.02)	1.00
AMF = AMF_{LRS} . AMF_S	1.43
Grades	
AMF (Exhibit 9)	1.015
Driveway Density	
$AMF = \frac{0.2 + [0.05 - 0.05\ln(ADT)]DD}{0.2 + [0.05 - 0.05\ln(ADT)](5)}$ (Equation [13])	1.0
Passing Lanes	
For conventional passing lane added in one direction of travel on the two-lane highway - AMF = 0.75 For short four-lane sections - AMF = 0.65	1.0
Two-Way Left-Turn Lanes	
$P_D = \frac{0.0047DD + 0.0024DD^2}{1.199 + 0.0047DD + 0.0024DD^2}$ (Equation [15]) $P_{LT/D}$ = 0.5	–
AMF = 1-0.7 P_D $P_{LT/D}$ (Equation [14])	1.0
Roadside Design	
Appendix C determine appropriate roadside hazard rating RHR from	5
$AMF = \frac{\exp(-0.6869 + 0.0668RHR)}{\exp(-0.4865)}$ (Equation [16])	1.143
Calibration Factor	
C_r (Appendix A)	1.10
Accident Prediction Model	
From Equation (1): N_{rs} = N_{br} C_r (AMF_{1r} AMF_{2r} … AMF_{nr})	0.14

Exhibit 17 presents the completed accident prediction worksheet for Example Problem 2.

Example Problem 3 addresses a four-leg signalized intersection.

EXAMPLE PROBLEM 3

The Highway Four-leg signalized intersection

The Question What is the predicted accident frequency of the signalized intersection for a particular year?

The Facts

- ✓ 4 legs
- ✓ Signalized intersection
- ✓ 90-degree intersection angle
- ✓ 2 left-turn lanes on major road
- ✓ 1 right-turn lane on major road
- ✓ Sight distance limited in one quadrant
- ✓ ADT of major road = 4000 veh/day
- ✓ ADT of minor road = 2000 veh/day
- ✓ Calibration factor = 1.3

Outline of Solution Base model, accident modification factors, and calibration factors will be calculated for the signalized intersection, and from these parameters the accident prediction model will be used to calculated the accident frequency.

Steps Presented in the intersection accident prediction worksheet (Exhibit 18)

Results The predicted accident frequency for two-lane intersection is 1.8 accidents per year

EXHIBIT 18. EXAMPLE PROBLEM 3—FOUR-LEG INTERSECTION

AT-GRADE INTERSECTION ACCIDENT PREDICTION WORKSHEET	
General Information	***Site Information***
Analyst Mary Smith Agency or Company State DOT Date Performed 02/07/02 Analysis Time Period ____________	Highway US 71 Roadway Section ____________ Jurisdiction ____________ Analysis Year 2002
Input Data	
Number of intersection legs (3 or 4)	4
Type of traffic control (minor-road STOP, all-way STOP, minor-road YIELD control, or signal)	signal
Intersection skew angle (absolute value in degrees of the difference between 90 degrees and the actual intersection angle)	0
Number of major-road approaches with intersection left-turn lanes (0, 1, or 2)	2
Number of major-road approaches with intersection right-turn lanes (0, 1, or 2)	1
Number of intersection quadrants with deficient intersection sight distance (0, 1, 2, 3, or 4)	1
Average ADT for major road	4000
Average ADT for minor road	2000
Base Model	
Three-leg STOP-controlled intersection $N_{bi} = \exp(-10.9+0.79\ln ADT_1+0.49\ln ADT_2)$ Equation (18)	–
Four-leg STOP-controlled intersection $N_{bi} = \exp(-9.34+0.60\ln ADT_1+0.0.61\ln ADT_2)$ Equation (20)	–
Four-leg signalized intersections $N_{bi} = \exp(-5.73+0.60\ln ADT_1+0.20\ln ADT_2)$ Equation (22)	2.152
Accident Modification Factors	
Intersection Skew Angle	
Three-leg STOP-controlled intersection AMF = exp(0.004SKEW) Equation (27)	–
Four-leg STOP-controlled intersection AMF = exp(0.0054SKEW) Equation (28)	–
Four-leg signalized intersections AMF = 1.0	1.0
Left-turn Lane AMF AMF for total intersection-related left-turn lanes (see Exhibit 10)	0.67
Right-turn Lane AMF The AMFs for right-turn lanes at intersection are: <u>Stop-controlled</u> 0.95 RTL on one major-road approach 0.90 RTLs on both major-road approaches <u>Signalized</u> 0.975 RTL on one major-road approach 0.95 RTLs on both major-road approaches	0.975
Intersection Sight Distance The AMFs for intersection sight distance at intersection with STOP or Yield control on the minor leg(s) are: 1.05 - sight distance limited in one quadrant 1.10 - sight distance limited in two quadrants 1.15 - sight distance limited in three quadrants 1.20 - sight distance limited in four quadrants An AMF of 1.00 is applicable to signal-controlled and all way STOP-controlled intersections	1.00
Calibration Factor	
C_i (Appendix A)	1.3
Accident Prediction Model	
From Equation (2): $N_{int} = N_{bi}\, C_i\, (AMF_{1i}\, AMF_{2i} \ldots AMF_{ni})$	1.8

Exhibit 18 presents the completed accident prediction worksheet for Example Problem 3.

Example Problem 4 addresses a three-leg STOP-controlled intersection.

EXAMPLE PROBLEM 4

The Highway Three-leg STOP-controlled intersection

The Question What is the predicted accident frequency of the stop-controlled intersection for a particular year?

The Facts

- ✓ 3 legs
- ✓ Minor-road stop control
- ✓ 30-degree skew angle
- ✓ No left-turn lanes on major road
- ✓ No right-turn lanes on major road
- ✓ Sight distance limited in two quadrants
- ✓ ADT of major road = 2000 veh/day
- ✓ ADT of minor road = 1000 veh/day
- ✓ Calibration factor = 1.5

Outline of Solution Base model, accident modification factors, and calibration factors will be calculated for the unsignalized intersection, and from these parameters the accident prediction model will be used to calculated the accident frequency.

Steps Presented in the Intersection Accident Prediction Worksheet (Exhibit 19)

Results The predicted accident frequency for two-lane intersection is 0.41 accidents per year

EXHIBIT 19. EXAMPLE PROBLEM 4—THREE-LEG INTERSECTION

AT-GRADE INTERSECTION ACCIDENT PREDICTION WORKSHEET	
General Information	***Site Information***
Analyst: Mary Smith Agency or Company: State DOT Date Performed: 02/07/02 Analysis Time Period: ____	Highway: US 71 Roadway Section: ____ Jurisdiction: ____ Analysis Year: 2002
Input Data	
Number of intersection legs (3 or 4)	3
Type of traffic control (minor-road STOP, all-way STOP, minor-road YIELD control, or signal)	Minor-road STOP
Intersection skew angle (absolute value in degrees of the difference between 90 degrees and the actual intersection angle)	30 degrees
Number of major-road approaches with intersection left-turn lanes (0, 1, or 2)	0
Number of major-road approaches with intersection right-turn lanes (0, 1, or 2)	0
Number of intersection quadrants with deficient intersection sight distance (0, 1, 2, 3, or 4)	2
Average ADT for major road	2000
Average ADT for minor road	1000
Base Model	
Three-leg STOP-controlled intersection $N_{bi} = \exp(-10.9+0.79\ln ADT_1+0.49\ln ADT_2)$ Equation (18)	0.221
Four-leg STOP-controlled intersection $N_{bi} = \exp(-9.34+0.60\ln ADT_1+0.61\ln ADT_2)$ Equation (20)	–
Four-leg signalized intersections $N_{bi} = \exp(-5.73+0.60\ln ADT_1+0.20\ln ADT_2)$ Equation (22)	–
Accident Modification Factors	
Intersection Skew Angle	
Three-leg STOP-controlled intersection AMF = exp(0.004SKEW) Equation (27)	1.127
Four-leg STOP-controlled intersection AMF = exp(0.0054SKEW) Equation (28)	–
Four-leg signalized intersections AMF = 1.0	–
Left-turn Lane AMF AMF for total intersection-related left-turn lanes (see Exhibit 10)	1.0
Right-turn Lane AMF The AMFs for right-turn lanes at intersection are: Stop-controlled 0.95 RTL on one major-road approach 0.90 RTLs on both major-road approaches Signalized 0.975 RTL on one major-road approach 0.95 RTLs on both major-road approaches	1.0
Intersection Sight Distance The AMFs for intersection sight distance at intersection with STOP or Yield control on the minor leg(s) are: 1.05 - sight distance limited in one quadrant 1.10 - sight distance limited in two quadrants 1.15 - sight distance limited in three quadrants 1.20 - sight distance limited in four quadrants An AMF of 1.00 is applicable to signal-controlled and all way STOP-controlled intersections	1.10
Calibration Factor	
C_i (Appendix A)	1.5
Accident Prediction Model	
From Equation (2): $N_{int} = N_{bi}\, C_i\, (AMF_{1i}\, AMF_{2i} \ldots AMF_{ni})$	0.41

Exhibit 19 presents the completed accident prediction worksheet for Example Problem 4.

Example Problem 5 combines the results of Example Problems 1 through 4 for a case where no site-specific accident history data are available.

EXAMPLE PROBLEM 5

The Highway Entire Project

The Question What is the expected accident frequency per year?

The Facts
The project is composed of the following sections:
- ✓ 2 roadway segments (presented in Example Problems 1 and 2)
- ✓ 2 intersections (presented in Example Problems 3 and 4)

Outline of Solution Calculate the accident frequency using the accident prediction models for all roadway segments and intersections comprising the project and then summing them up to get the total accident frequency for the entire project

Steps Presented in the Project Accident Prediction Worksheet

Results The estimated accident frequency for the entire two-lane project is 5.1 accidents per year

EXHIBIT 20. EXAMPLE PROBLEM 5

PROJECT ACCIDENT PREDICTION WORKSHEET	
General Information	***Site Information***
Analyst Mary Smith Agency or Company State DOT Date Performed 02/07/02 Analysis Time Period ______________________	Highway US 71 Roadway Section ______________________ Jurisdiction ______________________ Analysis Year 2002
Input Data	
Sum of accident prediction values for all roadway segments comprised by the project: ΣN_{rs}	3.0
Sum of accident prediction values for all at-grade intersections comprised by the project: ΣN_{int}	2.2
Accident Prediction Model for an entire project	
From Equation (3): $N_t = \Sigma N_{rs} + \Sigma N_{int}$	5.2

EXAMPLE PROBLEM 6

Example Problem 6 combines the results of Example Problems 1 through 4 for a case where site-specific accident history data are available.

The Highway Entire Project

The Question Considering the predicted values presented in Example Problems 1 through 4 and the observed values presented here, calculate the expected accident frequency for a three-year period using the EB procedure. For simplicity, assume the same expected number of accidents for each of the three years, ADT of 7000 for both roadway segments, and major road volumes of 4000 and minor road volumes of 2000 for both intersections.

The Facts

The project is composed of the following sections:

- ✓ 2 roadway segments (presented in Example Problems 1 and 2)
- ✓ 2 intersections (presented in Example Problems 3 and 4)
- ✓ 3-year analysis period

The following accident frequencies were observed:

ROADWAY SEGMENT 1

	Year 1	Year 2	Year 3
Observed Total	3	3	4
Observed F+I	1	1	2
Observed PDO	2	2	2

ROADWAY SEGMENT 2

	Year 1	Year 2	Year 3
Observed Total	1	0	1
Observed F+I	1	0	0
Observed PDO	0	0	1

FOUR-LEG SIGNALIZED INTERSECTION

	Year 1	Year 2	Year 3
Observed Total	3	4	2
Observed F+I	1	2	1
Observed PDO	2	2	1

THREE-LEG STOP-CONTROLLED INTERSECTION

	Year 1	Year 2	Year 3
Observed Total	2	3	3
Observed F+I	1	1	1
Observed PDO	1	2	2

Outline of Solution Calculate the expected accident frequency for the roadway segments and intersections using the EB procedure. Combine them with the predicted number using the safety prediction methodology. Finally, calculate the expected accident frequency for the entire project by using Equations (29) through (35). If a specific improvement were proposed for this site, the expected accident frequency *after* the improvement would be computed with Equation (36).

Steps Presented in the section entitled Safety Prediction When Site-Specific Accident History Data are Available.

Results The estimated accident frequency for the entire two-lane project is 20.2 accidents for a three-year period or 6.7 accidents per year, including 2.4 fatal and injury accidents per year and 4.3 property damage only accidents per year.

EB CALCULATION FOR EXAMPLE PROBLEM 6

Roadway Segment 1

Year	Year 1	Year 2	Year 3					
Calibration Factor	1.1	1.1	1.1					
ADT	7000	7000	7000					
Accident Frequency				***Sum***	***Weights***[c]	***LL***	***E***	E_{corr}
Predicted Total Seg 1[a]	2.769	2.769	2.769	8.307	0.429	1.5	9.273	9.273
Predicted F+I[b]	0.889	0.889	0.889	2.667	0.701	1.5	3.066	3.203
Predicted PDO[b]	1.880	1.880	1.880	5.640	0.526	1.5	5.811	6.070
Observed Total	3	3	4	10				
Observed F+I	1	1	2	4				
Observed PDO	2	2	2	6				

[a] From Exhibit 16.
[b] Based on 32.1 percent fatal and injury accidents and 67.9 percent property-damage-only accidents for roadway segments from Exhibit 2.
[c] From Equation (30) with k = 0.24 for roadway segments from Exhibit 15.

Roadway Segment 2

Year	Year 1	Year 2	Year 3					
Calibration Factor	1.1	1.1	1.1					
ADT	7000	7000	7000					
Accident Frequency				***Sum***	***Weights***[c]	***LL***	***E***	E_{corr}
Predicted Total Seg 2[a]	0.137	0.137	0.137	0.411	0.503	0.1	1.201	1.201
Predicted F+I[b]	0.044	0.044	0.044	0.132	0.759	0.1	0.341	0.451
Predicted PDO[b]	0.093	0.093	0.093	0.279	0.599	0.1	0.860	0.750
Observed Total	1	0	1	2				
Observed F+I	1	0	0	1				
Observed PDO	0	0	1	1				

[a] From Exhibit 17.
[b] Based on 32.1 percent fatal and injury accidents and 67.9 percent property-damage-only accidents for roadway segments from Exhibit 2.
[c] From Equation (30) with k = 0.24 for roadway segments from Exhibit 15.

Four-leg Signalized Intersection

Year	Year 1	Year 2	Year 3					
Calibration Factor	1.3	1.3	1.3					
ADT major	4000	4000	4000					
ADT minor	2000	2000	2000					
Accident Frequency				***Sum***	***Weights***[c]	***LL***	***E***	E_{corr}
Predicted Total[a]	1.919	1.919	1.919	5.757	0.612	1.0	7.015	7.015
Predicted F+I[b]	0.723	0.723	0.723	2.170	0.807	1.0	2.523	2.782
Predicted PDO[b]	1.196	1.196	1.196	3.587	0.717	1.0	3.987	4.233
Observed Total	3	4	2	9				
Observed F+I	1	2	1	4				
Observed PDO	2	2	1	5				

[a] From Exhibit 18.
[b] Based on 37.7 percent fatal and injury accidents and 62.3 percent property-damage-only accidents for four-leg signalized intersections from Exhibit 2.
[c] From Equation (30) with k = 0.11 for four-leg signalized intersections from Exhibit 15.

Three-leg STOP-controlled Intersection

Year	Year 1	Year 2	Year 3					
Calibration Factor	1.5	1.5	1.5					
ADT major	4000	4000	4000					
ADT minor	2000	2000	2000					
Accident Frequency				***Sum***	***Weights***[c]	***LL***	***E***	***E_{corr}***
Predicted Total[a]	0.323	0.323	0.323	0.969	0.656	1.0	2.697	2.697
Predicted F+I[b]	0.129	0.129	0.129	0.386	0.828	1.0	0.664	0.867
Predicted PDO[b]	0.194	0.194	0.194	0.583	0.760	1.0	1.402	1.830
Observed Total	2	3	1	6				
Observed F+I	1	1	0	2				
Observed PDO	1	2	1	4				

[a] From Exhibit 19.
[b] Based on 39.8 percent fatal and injury accidents and 60.2 percent property-damage-only accidents for three-leg STOP-controlled intersections from Exhibit 2.
[c] From Equation (30) with k = 0.54 for three-leg STOP-controlled intersections from Exhibit 15.

Entire Project

	Total	**F+1**	**PDO**
Roadway Segment 1	9.273	3.203	6.070
Roadway Segment 2	1.201	0.341	0.860
4-leg signalized intersection	7.015	2.782	4.233
3-leg STOP-controlled intersection	2.697	0.867	1.830
Combined	20.186	7.193	12.993

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APPENDIX A. CALIBRATION PROCEDURE TO ADAPT THE SAFETY PREDICTION METHODOLOGY TO THE DATA OF A PARTICULAR HIGHWAY AGENCY

Appendix A presents a calibration procedure. This procedure determines the value of C_r in Equation (1) and C_i in Equation (2) so that the methodology can be adapted to the local conditions experienced by a particular highway agency.

This appendix presents a calibration procedure for use with the safety prediction methodology. The purpose of the calibration procedure is to allow potential users of the algorithm to scale the accident predictions to be suitable for the roads under the jurisdiction of their agency using the calibration factors, C_r and C_i, shown in Equations (2) and (3).

The base models that form a key element of the safety prediction methodology are based on data from several States. The roadway section base models were based on data from Minnesota and Washington, but are implemented in the safety prediction methodology for Minnesota conditions. The base models for STOP-controlled intersections are based on Minnesota data, and the base models for signalized intersections are based on combined data from California and Michigan.

The calibration procedure provides a method for highway agencies other than those identified above to adapt the safety prediction methodology to their own safety conditions. Because safety conditions change over time, even a state whose data were used in the development of the base models should consider applying the calibration procedure to update the calibration factors every 2 or 3 years.

Safety conditions and the resulting accident rates and distributions of accident severities and accident types on rural two-lane highways vary substantially from one highway agency to another. Some of these variations are due to geometric design factors, such as differences in the distributions of lane and shoulder width, and differences in terrain, which lead to differences in horizontal and vertical alignment. These geometric design factors are accounted for by the safety prediction methodology and should not require explicit calibration to allow the methodology to be used.

By contrast, there are several factors that lead to safety differences between highway agencies in different geographical areas that are not directly accounted for by the safety prediction methodology. These include:

- Differences in climate (i.e., exposure to wet pavement and snow-and-ice-covered pavement conditions).
- Differences in animal populations that lead to higher frequencies of collisions with animals in some states than in others.
- Differences in driver populations and trip purposes (i.e., commuter vs. commercial travel vs. recreational travel).
- Accident reporting thresholds established by state law (i.e., minimum property damage threshold that requires reporting of an accident).
- Accident investigation practices (i.e., some police agencies are much more diligent about investigating and reporting property-damage-only collisions than others).

The calibration procedure is intended to account for these differences and provide accident predictions that are comparable to the estimates that a highway agency would obtain from its own accident records system.

For many states, development of statewide calibration factors for rural two-lane highways may be sufficient. In other states, it may be desirable to determine calibration factors for individual highway district, climate zones, or other geographical regions within the state. For example, a state that includes both plains and mountainous regions might develop separate calibration factors for each region.

HOW DOES THE CALIBRATION PROCEDURE AFFECT THE ACCIDENT PREDICTIONS?

The calibration procedure is implemented by determining the value of calibration factors for roadway sections and at-grade intersections from comparison of their own data to estimates from the safety prediction methodology. The calibration factors are incorporated in the safety prediction methodology in the following fashion for roadway segments and at-grade intersections, respectively:

$$N_{rs} = N_{br}C_r(AMF_{1r}AMF_{2r}\ldots AMF_{nr}) \quad \text{(A-1)}$$

$$N_{int} = N_{bi}C_i(AMF_{1i}AMF_{2i}\ldots AMF_{ni}) \quad \text{(A-2)}$$

where:

C_r = calibration factor for roadway sections developed for use in a particular geographical area; and
C_i = calibration factor for at-grade intersections developed for use in a particular geographical area.

The procedures for estimating values of C_r and C_i for a particular location are presented below.

The calibration procedure also permits a highway agency to modify the basic accident severity distribution for rural two-lane highways presented in Exhibit 2 and the basic accident type distribution for rural two-lane highways presented in Exhibit 3 based on their own data.

SHOULD THE SAFETY PREDICTION METHODOLOGY BE USED WITHOUT CALIBRATION?

The use of the safety prediction methodology without calibration is not recommended.

It is possible to use the safety prediction methodology without calibration, but this is not recommended. Using the safety prediction methodology without calibration requires the user to accept the assumption that, for their agency, $C_r = 1.0$, $C_i = 1.0$, and the accident severity and accident type distributions for two-lane highways are identical to those shown in Exhibits 2 and 3, respectively. These assumptions are unlikely to be correct for any individual highway agency and are unlikely to remain correct over time. Even a minimal calibration effort (referred to later in this appendix as level 1 calibration) is likely to produce far more satisfactory results than using the algorithm without calibration.

HOW OFTEN SHOULD THE SAFETY PREDICTION METHODOLOGY BE CALIBRATED?

The safety prediction methodology should be recalibrated every 2 or 3 years.

The recommended calibration procedure uses the three most recent years of accident data for the highway agency's rural two-lane highway system. Recalibration every 2 or 3 years is recommended. Recalibration every year is not necessary because it is unlikely that adding a new year of data and dropping the oldest of the three years used for calibration in the previous year will change the calibration factors substantially.

RECOMMENDED CALIBRATION PROCEDURES

It is neither necessary nor recommended that users of the safety prediction methodology generate new base. While such models could be developed using available accident, roadway, and traffic data and appropriate statistical analysis procedures the improvement in predictive ability over using the existing base models with appropriate calibration factors is likely to be minimal. It is definitely not recommended for users to change the accident modification factors in the safety prediction methodology. These AMFs are based on a compilation of the best available research, and they will be updated as new research becomes available. Rather, it is recommended that users apply the calibration procedures presented here to estimate the values of calibration factors, C_r and C_i, that can be used to adapt the outputs from the safety prediction methodology to the safety conditions experienced by an individual highway agency.

CALIBRATING THE ROADWAY SEGMENT SAFETY PREDICTION METHODOLOGY

Two levels of calibration procedures are available. The levels vary in terms of the effort required and data requirements. The choice of levels depends on:

- Type of data elements maintained within the existing traffic records systems.
- Existence, quality, and coverage of roadway, and traffic files.
- Availability and quality of accident data.
- Skills of personnel who will perform the calibration.
- Level of effort and personnel resources that the user is willing to commit to calibration.

The minimum data requirements and anticipated effort for each calibration process level are specified in Exhibit A-1. Level 1 is deemed the minimum and, compared to the other level, the easier calibration to perform. Level 2 requires more effort, but with a corresponding gain in accuracy. It is strongly recommended that the models NOT be used without calibration. Attempting to calibrate using procedures less stringent than the Level 1 procedure is strongly discouraged.

There are two levels of calibration procedure. Level 2 requires more detailed data than Level 1.

EXHIBIT A-1. MINIMUM REQUIREMENTS FOR CALIBRATION LEVELS 1 AND 2

Calibration process*	Minimum requirements	Anticipated effort for calibration
Level 1	The user must have the ability to: (1) stratify all two-lane rural roads by ADT; and (2) identify all nonintersection related accidents reported on those roads.	Minimal
Level 2	Level 1 requirements + the user must have the ability to: (3) stratify all two-lane rural roads by ADT, shoulder width, and lane width.	Moderate

* to be selected by the user.

Exhibit A-2 identifies the data elements that must be available with an agency's traffic records systems to complete each calibration level. The procedures to perform calibration for each level involve five steps shown in Exhibit A-3. The only difference between the two levels is that, in Level 2, Step 1 will develop estimates of miles of roadway by lane and shoulder width, as well as by curve and grade.

EXHIBIT A-2. DATA NEEDS FOR CALIBRATION LEVELS 1 AND 2

	Type of data	Data element	Level 1	Level 2A
Required	Accident records	Relationship of accidents to intersections or junctions	x	x
	Traffic volume files	ADT	x	x
	Roadway inventory files	Lane width Shoulder width		x x
Desirable	Alignment inventory files	Horizontal curve data; Grade and vertical curve data	x x	x x
	Access point	Driveways	x	x

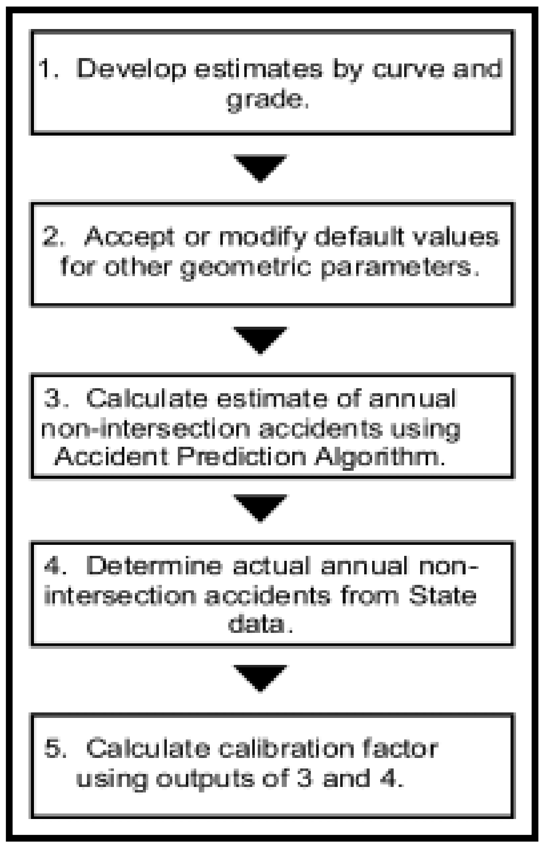
ROAD SYSTEM TO BE USED IN CALIBRATION PROCESS

It is important to recognize that there are variations among highway agency record systems. For example, some highway agencies include only roads under their own agency's jurisdiction in their traffic records systems. Other state agencies have records systems that also include local roads that are maintained by counties and municipalities. Calibration can be performed using whatever rural two-lane road system the user wishes to apply the safety prediction methodology to, as long as the data are accurate. Specifically, the following should exist:

- A reliable inventory of paved roads.
- Reliable counts of ADT and accidents that can be assigned to specific sections of a highway.
- Ability to stratify sections of highways into different highway types (i.e., the ability to distinguish rural two-lane highways from their highway types).

Exhibit A-3 presents a flow diagram for the calibration procedure.

EXHIBIT A-3. FLOW DIAGRAM OF CALIBRATION PROCEDURE



It should be noted that the base models used in the safety prediction methodology were developed for state primary routes that generally had 55-mi/h speed limits.

If an agency has accurate data for county highways and higher order routes but not for municipal highways, then the calibration process should not use municipal or township highways. Rather, data for only the county highways and higher order routes should be used. For example, Utah has data for 12,800 mi of paved roadways under state jurisdiction and another 32,000 mi of roadways not under state jurisdiction. A complete roadway inventory to which accidents can be linked is available for the 12,800-mi system of state roadways, but the other 32,000 mi have only "zone" records, that do not permit accident records to be linked to specific roadway sections. Consequently, any calibration of the accident prediction model with these data should use only the 12,800 mi of roadway under state jurisdiction.

Only paved two-lane highways should be considered in the calibration process.

LEVEL 1 CALIBRATION PROCESS FOR ROADWAY SEGMENT ACCIDENT PREDICTION USING ADT ONLY

A Level 1 calibration procedure for roadway segments is presented here.

Step 1. Develop Estimates of Paved Rural Two-Lane Highway Mileage by Curve and Grade. The user will first need to estimate the following for all paved rural two-lane highways for each of five ADT groups:

- < 1,000 veh/day
- 1,000-3,000 veh/day
- 3,001-5,000 veh/day
- 5,001-10,000 veh/day
- > 10,000 veh/day

For Highway Agencies With Alignment (Curve and Grade) Inventory Files

If a highway agency has curve and grade inventory files for paved rural two-lane highways, then it will be possible to calculate the necessary alignment data to perform the calibration. Using their horizontal curve inventory data, the user should first calculate the number of miles of tangent roadway, the number of miles of curved roadway, and the average degree of curve for horizontal curves by ADT interval, using the format shown in Exhibit A-4. Exhibit A-4, and subsequent exhibits in this appendix, are presented to illustrate the format in which the calibration calculations should be made; the blank spaces in the tables may be filled in by users of the calibration process. Using the available vertical alignment (grade) inventory data files, the user should then calculate the number of miles of two-lane rural roads that are not on grade (e.g., level), the number of miles with nonzero grades, the average percent grade for the miles with nonzero grades, and the overall average percent grade as shown in Exhibit A-5.

EXHIBIT A-4. ESTIMATE MILEAGE BY ADT LEVEL AND HORIZONTAL ALIGNMENT

ADT interval	Number of tangent miles	Number of curved miles	Average degree of curvature for curved miles (D)	Average radius of horizontal curve[a]	Average length of curve
< 1000					
1,001-3,000					
3,001-5,000					
5,001-10,000					
> 10,000					

[a] Calculated as 5729.58 / (D).

EXHIBIT A-5. ESTIMATE MILEAGE BY ADT LEVEL AND VERTICAL ALIGNMENT

ADT interval	Number of level miles (M_l)	Number of miles on grade (M_g)	Average percent grade for miles on grade (P_g)	Average percent grade[a]
< 1000				
1,001-3,000				
3,001-5,000				
5,001-10,000				
> 10,000				

[a] Calculated as $[(M_l) * (0) + (M_g) * (P_g)] / [M_l + M_g]$.

For Highway Agencies Without Alignment (Curve and Grade) Inventory Files

Highway agencies without curve or grade files can use an estimation procedure that will calculate "default" values for curve and grade mileages and average degree of curve and percent grade values based on the percent of rural two-lane miles that fall into each of the three terrain groups—flat, rolling, and mountainous. Thus, the user should estimate the mileage by ADT interval and the percentage of mileage in flat, rolling, and mountainous terrain; these percentages can be derived from the FHWA Highway Performance Monitoring System (HPMS) data. Then, the user will need to determine the mileages by ADT intervals and the percentages of level, rolling, and mountainous terrain.

Default values for the percentage of tangent and curved miles and the average degree of curvature for the curved miles are based on analyses of states in the FHWA Highway Safety Information System (HSIS) database which had both a curve file and terrain information. Based on these analyses, default values for proportion of two-lane rural miles that are curved and the corresponding average degree of curvature are:

- Flat: percent of nontangent miles = 19 percent; average degree of curvature = 2°.
- Rolling: percent of nontangent miles = 24 percent; average degree of curvature = 4°.
- Mountainous: percent of nontangent miles = 38 percent; average degree of curvature = 8°.

Similarly, information on default values for percent of nonflat miles and average grade for nonflat roadways from HSIS States were used to calculate the following default values:

- Flat: percent of nonflat miles = 87 percent; average grade = 1.5 percent.
- Rolling: percent of nonflat miles = 91 percent; average grade = 2.0 percent.
- Mountainous: percent of nonflat miles = 97 percent; average grade = 3.7 percent.

The blank spaces in Exhibits A-6 and A-7 are intended to be filled in by the user in performing the calibration procedure.

Exhibits A-6 and A-7 illustrate the data that are needed.

EXHIBIT A-6. ESTIMATE MILEAGE BY ADT INTERVAL

ADT interval	Estimated miles of paved, two-lane rural highways
< 1,000	
1,000-3,000	
3,001-5,000	
5,001-10,000	
> 10,000	

EXHIBIT A-7. ESTIMATE PROPORTION OF MILEAGE BY TERRAIN

Terrain	Proportion of paved, two-lane rural highways (percentage)
Flat	
Rolling	
Mountainous	
Total	100%

These values in Exhibits A-6 and A-7 should then be used to obtain estimates of the following:

- Number of miles of tangent roadway.
- Number of miles of roadway on horizontal curves.
- Average degree of curvature for horizontal curves.
- Average radius of horizontal curves.
- Average length of horizontal curves.
- Number of miles if level roadway.
- Number of miles of roadway on grade.
- Average percent grade for roadway on grade.
- Statewide or areawide average percent grade.

Step 2. Accept or Modify Default Values for Other Geometric Parameters. In addition to the values of curvature and grade developed in the proceeding step, the calibration procedure requires other geometric parameters. Using data from a sample of highway agencies during the calibration procedure development, it has been found reasonable to use the following default values for these parameters:

- Shoulder type = paved.
- Driveway density = 5 driveways/mi.
- Passing lane = not present.
- Short four-lane section = not present.
- Two-way left turn lanes = not present.
- Roadside hazard rating = 3.
- For horizontal curves:
  - no spiral transition present; and
  - superelevation is not deficient (e.g., AMF = 1.0).

For Level 1 calibration (which does not require data to be input for lane width and shoulder width), the following default values were estimated based on average values for two-lane highways obtained from eight HSIS States and are recommended for use:

ADT interval (Vehicles/day)	Default values for level 1 calibration		
	ADT (vehicles/day)	Lane width (ft)	Shoulder width (ft)
< 1000	400	11	3.5
1,000-3,000	1800	11.5	5
3,001-5,000	3900	12	5
5,001-10,000	6900	12	6.25
> 10,000	13800	12	6.5

The user may accept these defaults as presented and proceed onward. However, if the user has a better estimate for a value (e.g., if average driveway density is known to be equal to 7 driveways/mi, rather than 5 driveways/mi), or if the predominant two-lane roadway design used in a particular jurisdiction differs from these assumed defaults (e.g., if the predominant rural two-lane highway shoulder type is unpaved, rather than paved), then the user should feel free to modify the defaults.

Step 3. Calculate Estimate of Annual Nonintersection Accidents Using the Safety Prediction Methodology. Using the roadway segment safety prediction

The blank spaces in Exhibit A-8 are intended to be filled in by the user in performing the calibration procedure.

methodology, calculate the estimated annual number of nonintersection accidents for tangents and horizontal curves. Then, sum the total. Exhibit A-8 illustrates how the predicted number of accidents per year can be determined by the calibration software.

EXHIBIT A-8. CALCULATE THE PREDICTED ANNUAL NUMBER OF NONINTERSECTION ACCIDENTS AS A FUNCTION OF ADT.

ADT (veh/day)	Assumed mean of ADT interval*	Mileage of rural two lane highways			Predicted number of nonintersection accident per year**		
		Tangent	Curve	Total	Tangent	Curve	Total
< 1,000	400						
1,000-3,000	1,800						
3,001-5,000	3,800						
5,001-10,000	7,000						
> 10,000	13,500						

* Generally the average is less than the midpoint of the ADT interval.

** Determined with the uncalibrated safety prediction methodology for roadway segments.

Step 4. Determine Actual Annual Nonintersection Accidents from State Data. Using data from the last three years, determine the actual number of nonintersection accidents per year that were reported on the rural two-lane highways. First, determine the number of total accidents on the selected rural two-lane highways. Then, deduct all accidents on those rural two-lane highways that were identified by the investigating officer as being “at intersection” or “intersection-related.”

With respect to this criterion, the user must determine the most appropriate field(s) to establish intersection-relatedness. For example, a highway agency may have a field for “type of event location” or “site location” or “relationship to junction” on its accident report form that includes categories such as intersection, junction area, nonjunction area, driveway access, and alley access. Some highway agencies have an explicit field for “relation to intersection” with categories for yes or no. The decision on which field to use is left to the user. It is important to note that driveway accidents are NOT considered intersection accidents and should NOT be excluded from the calibration data for roadway segments. Driveway accidents were included in the data set from which the roadway segment base model was developed and, therefore, driveway accidents should not be excluded with intersection accidents.

Step 5. Calculate Calibration Factor Using Outputs of Steps 3 and 4. Calculate the calibration factor (C_r) as the ratio of the total number of reported nonintersection accidents (from Step 3) to the total number of predicted nonintersection accidents (from step 2).

LEVEL 2 CALIBRATION PROCESS FOR ROADWAY SEGMENT ACCIDENT PREDICTION USING ADT, LANE WIDTH, AND SHOULDER WIDTH

A Level 2 calibration procedure for roadway segments is presented here.

Step 1. Develop Estimates of Mileage by Curve and Grade and Lane and Shoulder Width. The user will first need to stratify the mileage of paved rural two-lane highways by the following factors and associated levels:

- ADT
  - < 1000 veh/day
  - 1,001-3,000 veh/day
  - 3,001-5,000 veh/day
  - 5,001-10,000 veh/day
  - >10,000 veh/day

- Lane Width
    - < 2.9 m (9.5 ft)
    - 9.5-10.5 2.9-3.2 m (9.5-10.5 ft)
    - 3.2-3.5 m (10.5-11.5 ft)
    - > 3.5 m (11.5 ft)

- Shoulder Width
    - < 0.9 m (3 ft)
    - 0.9-1.5 m (3-5 ft)
    - 1.5-2.1 m (5-7 ft)
    - > 2.1 m (7 ft)

- Horizontal Alignment
    - tangent
    - curve

For Highway Agencies With Alignment (Curve and Grade) Inventory Files

If the highway agency has curve and grade inventory files, then it will be possible to calculate the necessary alignment data to perform the calibration. Using the horizontal curve inventory data, the user should first estimate the number of miles of tangent roadway, the number of miles of curved roadway, and the average degree of curvature for horizontal curves for each unique combination of ADT interval, lane width, and shoulder width. Exhibit A-9 illustrates this for a portion of all possible combinations.

Using the available vertical alignment (grade) inventory data files, the user should then calculate the number of miles of two-lane rural roads that are not on grade (e.g., level), the number of miles with nonzero grades, the average percent grade for the roadways with nonzero grades, and the overall average percent grade as shown in Exhibit A-10.

For simplification purposes, it can be assumed that the average percent grade computed for an ADT interval is equally applicable across lane widths and shoulder widths within that interval. For example, consider the case where 1.9 percent is computed as the average percent grade for all two-lane rural roads within the < 1000 ADT interval. The 1.9 percent grade can be assumed for all lane and shoulder width combinations having ADTs less than 1,000 veh/day, as illustrated in Exhibit A-11.

For Highway Agencies Without Alignment (Curve and Grade) Inventory Files

Highway agencies without curve or grade files can use an estimation procedure that includes default values for curve and grade mileages and average degree of curve and percent grade values based on the percent of rural two-lane miles that fall into each of the three terrain groups-flat, rolling, and mountainous. Thus, the user needs to estimate the mileage by ADT interval, lane width, and shoulder width, and the percentage of mileage in flat, rolling, and mountainous terrains (which can be derived from HPMS data). Then, the user will need to enter the mileages by ADT intervals and the flat, rolling, and mountainous percentages into tables like Exhibits A-12 and A-13.

Default values for percent of tangent and curved miles and the average degree of curvature for the curved miles were based on analyses data from states in the HSIS database which had both a curve file and terrain information. Based on these analyses, default values for proportion of two-lane rural miles that are curved and the average degree of curvature for these miles are as follows:

- Flat: percent of nontangent miles = 19 percent; average degree of curvature = 2°.

- Rolling: percent of nontangent miles = 24 percent; average degree of curvature = 4°.
- Mountainous: percent of nontangent miles = 38 percent; average degree of curvature = 8°.

The blank spaces in Exhibit A-9 are intended to be filled in by the user in performing the calibration procedure.

EXHIBIT A-9. DEVELOP ESTIMATES REQUIRED FOR ALIGNMENT COMPONENT OF THE PROCEDURE

ADT interval	Lane width (ft)	Shoulder width (ft)	Number of miles on tangent	Number of miles on horizontal curves	Average degree of curvature (D)	Average radius of horizontal curve[a] (ft)	Average length of curve (mi)
< 1000	< 9.5	< 3					
		3 to 5					
		5 to 7					
		> 7					
	9.5 to 10.5	< 3					
		3 to 5					
		5 to 7					
		> 7					
	10.5 to 11.5	< 3					
		3 to 5					
		5 to 7					
		> 7					
	> 11.5	< 3					
		3 to 5					
		5 to 7					
		> 7					
1,001 to 3,000	< 9.5	< 3					
		3 to 5					
		5 to 7					
		> 7					
	9.5 to 10.5	< 3					
		3 to 5					
		5 to 7					
		> 7					
	10.5 to 11.5	< 3					
		3 to 5					
		5 to 7					
		> 7					
	> 11.5	< 3					
		3 to 5					
		5 to 7					
		> 7					

[a] Calculated as 5729.58 / (D).

EXHIBIT A-10. ESTIMATE MILEAGE BY ADT LEVEL AND VERTICAL ALIGNMENT

ADT interval	Number of miles of level roadway (M_l)	Number of miles on grade (M_g)	Average percent grade for miles of roadway on grade (P_g)	Average percent grade[a]
< 1000				
1,001-3,000				
3,001-5,000				
5,001-10,000				
> 10,000				

[a] Calculated as $[(M_l) * (0) + (M_g) * (P_g)] / [M_l + M_g]$.

The blank spaces in Exhibit A-10 are intended to be filled in by the user in performing the calibration procedure.

EXHIBIT A-11. ILLUSTRATION OF HOW AVERAGE PERCENT GRADE CAN BE APPLIED ACROSS LANE AND SHOULDER WIDTH COMBINATIONS

AADT (vehicles per day)	Average percent grade (%)															
	Lane width															
	< 9.5 ft				9.5 to 10.5 ft				10.5 to 11.5 ft				> 11.5 ft			
	Shoulder width (ft)															
	< 3	3-5	5-7	> 7	< 3	3-5	5-7	> 7	< 3	3-5	5-7	> 7	< 3	3-5	5-7	> 7
< 1,000	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9

EXHIBIT A-12. ESTIMATE PROPORTION OF MILEAGE BY TERRAIN

Terrain	Proportion of paved, two-lane rural highways (percentage)
Flat	
Rolling	
Mountainous	
Total	100%

The blank spaces in Exhibit A-12 are intended to be filled in by the user in performing the calibration procedure.

The blank spaces in Exhibit A-13 are intended to be filled in by the user in performing the calibration

EXHIBIT A-13. ESTIMATE MILEAGE BY ADT INTERVAL, LANE, AND SHOULDER WIDTHS

AADT (Vehicles per day)	Mileage of paved, two-lane rural roads															
	Lane Width < 9.5 ft				9.5 < Lane Width < 10.5 ft				10.5 < Lane Width < 11.5 ft				Lane Width > 11.5 ft			
	Shoulder Width (ft)															
	<3	3-5	5-7	>7	<3	3-5	5-7	>7	<3	3-5	5-7	>7	<3	3-5	5-7	>7
< 1,000																
1,001-3,000																
3,001-5,000																
5,001-10,000																
> 10,000																

1 ft = 0.305 m

Similarly, information on default values for percent of nonflat miles and average grade for nonflat mileage from HSIS States were used to calculate the following default values:

- Flat: percent of nonflat miles = 87 percent; average grade = 1.5 percent.
- Rolling: percent of nonflat miles = 91 percent; average grade = 2.0 percent.
- Mountainous: percent of nonflat miles = 97 percent; average grade = 3.7 percent.

The values in Exhibits A-12 and A-13 can then be used by the calibration software to obtain estimates of the following:

- Number of tangent miles
- Number of curved miles
- Average degree of curvature for horizontal curves
- Average radius of horizontal curve
- Average length of curve
- Number of level miles
- Number of miles on grade
- Average percent grade for miles on grade
- Statewide average percent grade

Step 2. Accept or Modify Default Values for Other Geometric Parameters. Next, the user will need to develop values for other input parameters of the roadway segment safety prediction methodology. Values for average percent grade, average length of curve, and average radius of curvature will have been developed in Step 1. For the purposes of calibration, it has been found to be reasonable to assume the following default values:

- Shoulder type = paved.
- Driveway density = 5 driveways per mile.
- Passing lane = not present.
- Short four-lane section = not present.
- Two-way left turn lanes = not present.
- Roadside hazard rating = 3.
- For horizontal curves:
  - no spiral transition present; and
  - superelevation is not deficient (e.g., AMF = 1.0).

Step 3. Calculate Estimate of Annual Nonintersection Accidents Using the Safety Prediction Methodology. Calculate the predicted annual number of nonintersection related accidents for tangents and curves using the roadway segment safety prediction methodology. Then, sum the total. Exhibit A-14 illustrates the procedure. The predicted number of total nonintersection accident rates will then be the sum of the number predicted in each line of the table presented in Exhibit A-14 (i.e., sum all calculated values in the final table column for all combinations of ADT, lane width, shoulder width, curve, and grade).

Step 4. Determine Actual Annual Nonintersection Accidents from State Data. Determine the number of nonintersection accidents on rural two-lane highways using three years of accident data. This is the same as Step 3 from the Level 1 calibration process, which was previously described.

Step 5. Calculate Calibration Factor Using Outputs of Steps 3 and 4. Calculate the calibration factor (C_r) as the ratio total number of reported nonintersection accidents on rural two-lane highways (from Step 4) to the predicted total number of nonintersection accidents on rural two-lane highways (from Step 3).

EXHIBIT A-14. PREDICTING TOTAL NONINTERSECTION ACCIDENTS AS A FUNCTION OF ADT, LANE WIDTH, AND SHOULDER WIDTH

ADT (veh per day)	Lane width (ft)	Shoulder width (ft)	Calculated mean ADT for each combination of ADT, lane width, and shoulder width	Mileage of rural two lane highways			Predicted number of nonintersection accidents per year**		
				Tangent	Curve	Total	Tangent	Curve	Total
< 1,000	< 9.5	< 3							
		3.1-5.0							
		5.1-7.0							
		> 7.0							
	9.5-10.5	< 3.0							
		3.1-5.0							
		5.1-7.0							
		> 7.0							
	10.5-11.5	< 3.0							
		3.1-5.0							
		5.1-7.0							
		> 7.0							
	> 11.5	< 3.0							
		3.1-5.0							
		5.1-7.0							
		> 7.0							
Continue Table for Other AADT Intervals									
		Predicted total number of nonintersection accidents =							

1 ft = 0.305 m 1 mi = 1.61 km

* To be calculated by safety prediction methodology, although the State will have to enter the mean ADT values for each interval.

** Determined with the uncalibrated safety prediction methodology for roadway segments.

The calibration procedure for intersections is presented here.

CALIBRATING THE AT-GRADE INTERSECTION SAFETY PREDICTION METHODOLOGY

A calibration procedure for at-grade intersections has also been developed. This procedure uses a five-step process analogous to the roadway segment calibration procedure presented above.

Step 1. Identify Intersection Sites. For each of the following intersection types, the user should identify a sample of intersections for which both intersecting roads are paved rural two-lane highways:

- Three-leg, STOP-controlled intersections.
- Four-leg, STOP-controlled intersections.
- Four-leg, signalized intersections.

Separate values of the calibration factor (C_i) are obtained for each intersection type.

It should be recognized that the current safety prediction methodology does not contain prediction algorithms for other types of rural road intersections, such as (1) five-leg intersections; (2) traffic circles/roundabouts; (3) three-leg signalized intersections; (4) intersections of two-lane roads with multilane roads; (5) uncontrolled or YIELD-controlled intersections; (6) intersections involving one-way streets; or (7) ramp terminals. In general, these types of intersections constitute a small percentage of all two-lane rural road intersections.

The desirable minimum sample sizes for calibration are suggested in Exhibit A-15.

EXHIBIT A-15. MINIMUM SAMPLE SIZES BY TYPE OF INTERSECTION

Type of Intersection	Suggested Minimum Sample Size
Three-leg STOP-controlled intersections	100
Four-leg STOP-controlled intersections	100
Four-leg signalized intersections	25

Users should identify the sample of their two-lane rural road intersections based on selected characteristics for each of the three intersection types (e.g., three-leg STOP-controlled, four-leg STOP-controlled, and four-leg signalized intersections). The most important characteristic is ADT.

It should be understood that there are other parameters used in the safety prediction methodology such as intersection skew angle, number of major approaches with left-turn lanes, and number of major approaches with right-turn lanes, among others. Moreover, data on several of these variables may even be available within the intersection inventory files of some highway agencies. However, because the research has found that ADT had the strongest predictive relationship with accidents compared to the other variables, it is recommended that the sampling strategy be based only on ADT.

For highway agencies with complete and accurate intersection inventory files, it may be possible to automate the sample identification process. For highway agencies that do not have intersection inventory files, it will not be possible to sample in proportion to known intersection distributions. Hence, a different sampling procedure applies. The two procedures are discussed separately in the following sections.

Sample Selection for Highway Agencies With Intersection Inventory Files

If a highway agency maintains an accurate and comprehensive intersection inventory file, which includes attribute data about the ADT on the major and minor roads, then the following process is applicable.

For all three- and four-leg STOP-controlled intersections, stratify intersections by ADT on the major road. Exhibit A-16 illustrates how this can be accomplished for the three- and four-leg STOP-controlled intersections. As shown, the user should calculate the proportion (relative percentage) of three-leg STOP-controlled intersections which fall into each major-road ADT group. The desired sample of 100 intersections should be divided into groups using these proportions.

For four-leg signalized intersections, both the major- and minor-road ADTs have a significant effect on accidents. Hence, for four-leg signalized intersections, sampling should consider both the major- and minor-road ADTs. Given that there are usually relatively few rural signalized intersections, major- and minor-road ADTs have been combined into a single factor, which can be subsequently used for sampling stratification. The factor is the sum of the average major-road ADT and the average minor-road ADT. Exhibit A-17 presents a numerical example of how this should be done for four-leg signalized intersections.

By way of an example, consider a situation in which a highway agency wants to sample intersections based on ADT and highway district. Exhibit A-18 illustrates how highway districts can be considered in the development of a sampling strategy for three-leg STOP-controlled intersections only in a State with three districts. The results of this exhibit can be compared with the top portion of Exhibit A-16 to illustrate how the desired stratification scheme for the sample can be further refined.

EXHIBIT A-16. EXAMPLE OF DESIRED SAMPLE STRATIFICATION OF THREE- AND FOUR-LEG STOP-CONTROLLED INTERSECTIONS BASED ON MAJOR ROAD ADT.

Intersection type	ADT on major road (vehicles/day)	Intersections of two-lane rural roads		
		Number	Relative percentage	Desired sample
Three-leg STOP-controlled intersections	< 1,000	1,095	18.3%	18
	1,001-3,000	1,443	24.1%	24
	3,001-5,000	1,641	27.4%	27
	5,001-10,000	887	14.8%	15
	10,001-15,000	574	9.6%	10
	> 15,000	347	5.8%	6
	Total	5,987	100.0%	100
Four-leg STOP-controlled intersections	< 1,000	874	21.0%	21
	1,001 - 3,000	777	18.6%	19
	3,001 - 5,000	1,219	29.2%	29
	5,001 - 10,000	489	11.7%	12
	10,001 - 15,000	544	13.0%	13
	> 15,000	267	6.4%	6
	Total	4,170	100.0%	100

EXHIBIT A-17. EXAMPLE OF DESIRED SAMPLE STRATIFICATION OF FOUR-LEG SIGNALIZED INTERSECTIONS BASED ON MAJOR ROAD ADT

Four-leg, signalized intersections	Sum of major- and minor-road ADTs	Intersections of two-lane rural roads		
		Number	Relative percentage	Desired sample
	< 15,000	49	36.0%	9
	≥ 15,000	87	64.0%	16
	Total	136	100.0%	25

After the sampling stratification is established, then the specific intersections within each of the cells must be identified. A random selection process should be employed. Within this context, the term random means that all intersection sites of the same type (e.g., either three-leg STOP-controlled intersections, four-leg STOP-controlled intersections, or four-leg signalized intersections) should have the same chance of being selected.

As an example, using the sampling stratification shown in Exhibit A-16, the names of all three-leg STOP-controlled intersections with major-road ADT less than 1,000 veh/day could be put into a hat and the names of 18 intersections could be drawn at random. The same procedure would be followed for each of the other ADT levels, and then repeated again for four-leg STOP-controlled and signalized intersections. The same "random draw" could be accomplished with a computerized sample by assigning a number to each three-leg STOP-controlled intersection with major-road ADT less than 1,000 veh/day and determining a ratio by dividing the total number of intersections in the file by 18. The first intersection selected would be the intersection whose number is closest to that ratio, the second selected is the intersection whose number is closest to twice that ratio, etc. For example, if there were 90 total intersection from which 18 were to be selected every fifth intersection should be chosen (i.e., 90/18=5).

EXHIBIT A-18. EXAMPLE OF DESIRED SAMPLE STRATIFICATION OF THREE-LEG STOP-CONTROLLED INTERSECTIONS BASED ON MAJOR-ROAD ADT AND HIGHWAY DISTRICT

ADT on major roads	State highway district	Intersections of two two-lane rural roads		
		Number	% Within state	Desired sample
< 1,000	District 1	620	10.4%	10
	District 2	339	5.7%	6
	District 3	136	2.3%	2
	Subtotal	**1,095**	**18.3%**	**18**
1,001-3,000	District 1	435	7.3%	7
	District 2	674	11.3%	11
	District 3	334	5.6%	6
	Subtotal	**1,443**	**24.1%**	**24**
3,001-5,000	District 1	592	9.9%	10
	District 2	527	8.8%	9
	District 3	522	8.7%	9
	Subtotal	**1,641**	**27.4%**	**27**
5,001-10,000	District 1	363	6.1%	6
	District 2	446	7.4%	7
	District 3	78	1.3%	1
	Subtotal	**887**	**14.8%**	**15**
10,001-15,000	District 1	185	3.1%	3
	District 2	334	5.6%	6
	District 3	55	0.9%	1
	Subtotal	**574**	**9.6%**	**10**
> 15,000	District 1	58	1.0%	1
	District 2	289	4.8%	5
	District 3	0	0.0%	0
	Subtotal	**347**	**5.8%**	**6**
Total for entire State		**5,987**		**100**

Sample Selection for Highway Agencies Without Intersection Inventory Files

For highway agencies without comprehensive or accurate intersection inventories, information about the existing distribution of intersections under that agency's jurisdiction may not be known. Hence, the task of identifying existing distributions on which to base the sampling strategy may be limited or even nonexistent. Moreover, it may not be possible to identify every intersection on two-lane rural roads, although one expects traffic signal inventory data would make a list of signalized intersections generally available.

When a comprehensive list of intersections is not available or cannot be created, then it will be necessary to identify and develop a sample of intersections from an identified sample of a sample of two-lane rural roadway segments. (It is assumed that the highway agency has the capability to identify, sort and develop a random sample of all two-lane rural roadway segments.) Using an approach similar to one previously described for highway agencies with intersection inventories, a sample of 100 two-lane rural road segments should be identified based on either (1) ADT alone; or (2) ADT plus additional factors such as highway district that the user deems necessary. (Thus, using the results shown in Exhibit A-16 for three- and four-leg STOP-controlled intersections in the lowest ADT groups, the user should sample approximately 20 intersections with ADTs less than 1,000 veh/day.)

The data collection teams should be dispatched to those two-lane rural roadway segments with instructions to collect data at the first three-leg STOP-controlled intersection and the first four-leg STOP-controlled intersection encountered on each segment. In this manner, data can be gathered on a sample of 100 intersections for two of the three intersection types.

As was noted earlier, it is reasonable to assume that traffic signal inventory information, even if in hard copy format, will be available to identify the locations of four-leg signalized intersections at which both the major and minor legs are two-lane rural roads. If the information is not adequate (e.g., cannot determine whether the intersecting roads are two-lane rural roads), then it may be necessary to use the random selection process described for three- and four-leg STOP-controlled intersections above. Based on the intersection inventory data from three HSIS states, there are relatively few four-leg signalized intersections of two-lane rural roads. Thus, the potential exists that the data collection team will have to drive long distances before encountering their first four-leg signalized intersection at which both legs are two-lane rural roads.

Additional Constraints with Respect to Final Selection of the Sample

It is important to recognize that regardless of how the sample is identified, the user should ensure that each selected site experienced no significant changes in geometry, traffic control, roadside improvements, or other factors during the three-year period corresponding the accident data (which will be discussed in Steps 4 and 5). In addition, it will be necessary to exclude intersections that have undergone changes since the end of that three-year period because measurements of skew angle and intersection sight distance taken today may not be representative of conditions that existed during the three-year period. By way of an example, assume that accident data from 2000, 2001, and 2002 are going to be used in the calibration. To be included in the sample, the intersection should not have undergone any major changes since January 1, 2000.

If an intersection is known to have had experienced a major change during the study period, then it should be excluded from the sample. Major changes at intersection sites include the following:

- Installation of traffic signal control
- Widening to provide more approach lanes and/or turn lanes
- Change from a two-way STOP control to an all-way STOP control
- Changes in intersection geometry (e.g., alignment or cross-section)

Step 2. Collect Data at Selected Intersections. Collect the following information for each intersection in the selected sample:

- Average ADT of major road
- Average ADT of minor road
- Intersection skew angle
- Number of quadrants with deficient sight distance
- Number of major-road approaches with left turn lanes
- Number of major-road approaches with right turn lanes
- Type of traffic control applies (e. g., minor-road or all-way STOP control)

Several of these variables are described below in more detail.

Average ADT of Major Road and Average ADT of Minor Road pertain to the bidirectional (i.e., two-way) ADT on the mainline and cross road, respectively. For intersections where the ADT on one leg of the major road differs from the ADT of the other leg of the major road, the average of the two values should be used. Similarly, if the ADT on one leg of a cross road at a four-leg intersection differs from the ADT on the other leg of the crossroad, then the average of the two values should be used.

Most importantly, the ADT should correspond to the accident data. For example, if the calibration is to be performed using accident data from 2000, 2001, and 2002, then the ADTs to be used in the safety prediction methodology should be the average of the ADTs for the major and minor roads at the selected intersection for the same years. When data for all of the selected years are missing or not available, then the user should use data for a year in the middle of the period if available, or the last year if a middle year is not available.

The skew angle is described above in the methodology discussion. The skew angle is the deviation of the intersection angle from the nominal or base angle of 90 degrees (i.e., a right angle). For a four-leg intersection where the angles of the intersection legs to the left and the right of the major road differ, they are averaged. For example, if one leg forms a 60 degree angle and the other intersects at 90 degrees, then the average would be 15 degrees [e.g., *(60-90)* / 2].

Step 3. Execute Safety Prediction Methodology. The data collected in Step 2 should be entered into tables. Data for each intersection within each of the three intersection types will be entered in a row of the table by itself. The safety prediction methodology will then be used to calculate the predicted number of annual intersection accidents for each intersection. The total number of predicted accidents for each of the three types of intersections will be obtained by summing the calculated predictions for all intersections of that type.

Step 4. Tally Reported Intersection Accidents. Determine the number of intersection-related accidents reported at these intersections over a period of three calendar years. An intersection-related accident is an accident that occurs at the intersection itself or an accident that occurs on an intersection approach with 250 ft of the intersection and is related to the presence of the intersection. The State should exercise its judgment to develop the criteria that best apply this definition to their available data. Within each intersection type, the three-year totals for intersection-related accidents will be divided by three to obtain annual counts. These annual counts should then be used in determining the calibration factor.

Step 5. Calculate Calibration Factors. For each intersection type, calculate the calibration factor (C_i) as the total number of reported annual intersection accidents (from Step 4) divided by the total number of predicted annual intersection accidents (from Step 3). As with the earlier roadway segment calibration, the user will then have the option of accepting the calculated factors or modifying them. Once accepted by the user, the values of the calibration factors for each intersection type should be entered into a file of default input values for the safety prediction methodology. In subsequent applications of the safety prediction methodology, these values of C_i will be used in applying Equation (A-2). Again, it is suggested that the calibration factors be updated every two to three years. The same sample of intersections can be used at two- to three-year intervals for this purpose.

CALIBRATION OF ACCIDENT SEVERITY DISTRIBUTION

The accident severity distribution is calibrated by calibrated Exhibit 2 with local values.

It is recommended that users of the safety prediction methodology replace the default accident severity distribution shown in Exhibit 2 with values specifically applicable to the rural two-lane highways under a particular agency's jurisdiction. In Step 3 of the preceding calibration procedures for roadway segments and Step 4 of the procedures for intersections, the user will have identified appropriate files of accidents for roadway segments and intersections. It is recommended that these accidents be used in determining the accident severity distributions to update Exhibit 2.

CALIBRATION OF ACCIDENT TYPE DISTRIBUTION

The accident type distribution is calibrated by updating Exhibit 3 with local data.

The default accident type distribution shown in Exhibit 3 can be calibrated by a user to obtain values specifically applicable to the rural two-lane highways under a particular agency's jurisdiction using a procedure that is entirely analogous to the procedure for accident severity distributions described above. The accident type distributions for both roadway segments and at-grade intersections in Exhibit 3 should be calibrated in this manner using the same accident data used to update Exhibit 2. It should be noted that the accident type distribution for roadway segments influences the AMFs for lane width, shoulder width, and shoulder type in the safety prediction methodology.

LOCAL CALIBRATION FACTORS

Development of local calibration factors should be considered when climate or driver factors in a local area are different from the highway agency jurisdiction as a whole.

In addition to the calibration process described in this appendix, which can be thought of as a global calibration of the safety prediction methodology, another form of calibration is possible. Specifically, predictions made with the methodology [including the calibration factors (C_r and C_i) can be further calibrated to existing local conditions by means of the EB procedure, which is described in Appendix B. Local calibration should be considered if there are local climate or driver factors—that would make safety conditions for a single project or a small area differ from the state or area as a whole. It is important to recognize that for projects in which existing accident histories can be used, weights are assigned to the outputs from the safety prediction methodology and the site-specific accident history within the EB procedure. Thus, a greater degree of importance can be assigned to site-specific accident histories than to the methodology-generated prediction.

For alternatives primarily on new alignment, the EB procedure does not apply because the site-specific accident history of the old alignment is not necessarily representative of conditions on the new alignment. Thus, such projects should be analyzed without the EB procedure, but using the applicable calibration factors, C_r and C_i. If the analyst is concerned that safety conditions in a particular local area may differ substantially from the conditions represented by the global calibration factors, a special calibration study for a local area (possibly with a reduced sample size of roadway segments and/or intersections) can be performed using the procedures presented in this appendix. This might be particularly suitable for smaller areas with distinct driver populations or climate conditions.