Knowledge Acquisition Methods for the IHDS Diagnostic Review Expert System

PUBLICATION NO. FHWA-RD-97-134

DECEMBER 1997

U.S. Department of Transportation
Federal Highway Administration

Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipients Catalog No.
FHWA-RD-97-134		

4. Title and Subtitle	5. Report Date
KNOWLEDGE ACQUISITION METHODS FOR THE IHSDM DIAGNOSTIC REVIEW EXPERT SYSTEM	December 1997
	6. Performing Organization Code
7. Author(s) Warren E. Hughes, Clint Schuckel, Michelle Smith, and Hugh W. McGee	8. Performing Organization Report No.
9. Performing Organization Name and Address Bellomo-McGee, Inc. (BMI) 8330 Boone Blvd., Suite 700 Vienna, VA 22182-2624	10. Work Unit No. (TRAIS) 3A5A
	11. Contract or Grant No. DTFH61-92-C-00172
12. Sponsoring Agency Name and Address Office of Safety and Traffic Operations R&D Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296	13. Type of Report and Period Covered Final Report December 1995 to July 1997
	14. Sponsoring Agency

15. Supplementary Notes

Contracting Officer's Technical Representative (COTR): Justin True, HSR-20. Dr. Alison Smiley, President of Human Factors North, prepared appendix B. Gary Shannon, P.E., prepared appendix C.

16. Abstract

The Federal Highway Administration's Interactive Highway Safety Design Model (IHSDM) is a suite of CADD-compatible programs that highway designers can use to evaluate the safety effects of various design alternatives. The IHSDM will include a Policy Review Module, a Design Consistency Module, a Driver/Vehicle Module, a Traffic Analysis Module, and an Accident Analysis Module. IHSDM development efforts have thus far been concentrated on two-lane rural roads. Current plans for the Accident Analysis Module consist of models to estimate the number and severity of accidents on specified roadway segments, a benefit/cost analysis model to evaluate alternate roadside designs, and an expert system that can evaluate a design alternative and identify geometric deficiencies that may impact safety. In this report, the term Diagnostic Review Component (DRC) is used to define this expert system. The key to the DRC will be the knowledge base that will be accessed to "flag" potential design-related safety deficiencies. In addition, the DRC will ultimately have the capability to provide users with suggested improvements that could mitigate the safety problems.

This report presents the results of a feasibility study of alternative methods for developing the knowledge base for the DRC. Alternative sources of knowledge that were reviewed included the following:

- Interviews with State highway design personnel and review of State highway safety improvement programs.
- Interviews with experts in safety, geometric design, accident investigation, traffic engineering, and human factors.
- In-depth investigations of accident sites.
- Review of highway safety research and safety-audit literature.

The advantages, disadvantages, and development implications for the expert system's knowledge base are discussed for each method. Findings from the feasibility investigations of each method are documented. Finally, recommendations for subsequent research, including a detailed experimental plan for the development of a prototype DRC, are presented.

17. Key Words	18. Distribution Statement
Interactive Highway Safety Design Model, Diagnostic Review Component, geometric design, expert system, knowledge acquisition, design review, forensic site investigations.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	241	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

(Revised September 1993)

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LIST OF ABBREVIATIONS

AAM	Accident Analysis Module
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
CADD	Computer-Aided Design and Drafting
COTR	Contracting Officer's Technical Representative
DOT	Department of Transportation
DRC	Diagnostic Review Component
DRES	Diagnostic Review Expert System
ERM	Empirical Review Module
FHWA	Federal Highway Administration
GIS	Geographic Information System
HSIP	Highway Safety Improvement Programs
HSIS	Highway Safety Information System
IDA	Information-Decision-Action
IHSDM	Interactive Highway Safety Design Model
ISD	Intersection Sight Distance
ITE	Institute of Transportation Engineers
MEV	Million Entering Vehicles
MUTCD	*Manual on Uniform Traffic Control Devices*
NCHRP	National Cooperative Highway Research Program
NYSDOT	New York State Department of Transportation
ODOT	Ohio Department of Transportation
PI	Principal Investigator
PRM	Policy Review Module
TCD	Traffic Control Devices
TRB	Transportation Research Board
TWG	Technical Work Group

CHAPTER 1. INTRODUCTION

During the highway design process, numerous decisions that affect future highway safety conditions are made. In many cases, trade-offs are made in the interest of cost. While the costs for additional right-of-way, construction, peripheral items, and even mitigation of environmental problems, such as wetlands and noise, can be estimated and factored into the analysis, costs for safety are not.

The underlying premise in highway design has been that if all minimum design standards are met, a minimal level of safety is achieved. Unfortunately, in many cases, this is not true. The acceptance of "across the board" minimum design standards can lead to the creation of potentially hazardous situations where certain combinations of geometric elements and/or features exist. Moreover, there are cases in which design exceptions and/or variances are proposed and granted, with the rationale that safety will not be inordinately compromised. However, no nationally accepted procedures explicitly evaluate highway design alternatives in terms of safety. Consequently, these design exception decisions are often made without the benefit of any substantiation or empirical evidence to the contrary.

While all drivers, occupants, and pedestrians must accept a certain degree of risk, the objective of good highway design is to minimize those risks. By providing improved tools that explicitly incorporate safety into the design process in a systematic manner, highway designers can make more informed decisions that ultimately enhance highway safety.

BACKGROUND

Recognizing these needs, the Federal Highway Administration (FHWA) has established a research program to develop the Interactive Highway Safety Design Model (IHSDM). The IHSDM will be a tool that designers and transportation professionals can apply within the Computer-Aided Design and Drafting (CADD) environment to assess the adequacy of the safety of alternative designs. The IHSDM is composed of six modules, one of which is the Accident Analysis Module (AAM). One element of the AAM is the Diagnostic Review Component (DRC). The FHWA's concept of the DRC envisions an "expert systems" approach utilizing a knowledge base of facts and rules.

OBJECTIVES

The objectives of this research were to: (1) investigate alternative methods for developing the knowledge base for the DRC, and (2) develop an experimental plan for constructing the knowledge base systematically. It should be noted that the objective of this research was not to develop the knowledge base. Rather, the research was more of a feasibility study to determine the advantages and disadvantages of potential methods that could be applied to developing the knowledge base.

ORGANIZATION OF THE REPORT

The remainder of this report is organized as follows: Chapter 2 describes the Interactive Highway Safety Design Model (IHSDM). It discusses the current vision and presents brief descriptions of the current modules. The chapter focuses primarily on the Accident Analysis Module (AAM) and introduces the Diagnostic Review Component (DRC).

Chapter 3 presents more detailed information on the expert systems approach and the stages of development. Expert systems literature is referenced to present methods of acquiring information for the knowledge base. Implications of an expert systems approach to the DRC are discussed. An overview of four potential methods for developing the knowledge base is presented in chapter 4. The critical issues related to this task are also discussed.

The four methods are described in much greater detail in chapters 5 through 8. Chapter 5 describes the feasibility of developing the knowledge base from expert interviews. Chapter 6 evaluates the usefulness of forensic investigations of accident-site locations using multidisciplinary teams. Chapter 7 addresses the potential for developing the data base from the literature, including accident and highway safety research documents and literature related to safety audits. The potential for developing the data base from highway safety improvement program data is examined in chapter 8.

A synthesis of the findings is presented in chapter 9. Recommendations for subsequent research are presented in chapter 10.

Appendix A presents a proposed experimental plan for the development of the DRC knowledge base. The proposed approach, a detailed work plan, and the estimated level of effort are provided in this appendix.

Appendices B and C present summaries of the field investigations conducted at four intersections in Minnesota. Appendix B was prepared by a human factors expert. Appendix C was prepared by a traffic engineer, who had experience in both highway design and forensic investigations of crashes.

Finally, appendix D presents an illustrative example of pages selected from Austroads' *Road Safety Audit* manual.

CHAPTER 2. DIAGNOSTIC REVIEW COMPONENT, IHSDM ACCIDENT ANALYSIS MODULE

Current highway design methodologies include formal procedures for the incorporation of several key variables and issues into the design process. These objectives of good design include maximizing safety, optimizing traffic operations, minimizing cost, maintaining air quality and other environmental standards, and minimizing impact to adjacent land uses and property owners. Each of these objectives is taken into consideration while designing a roadway, according to design standards and policies set forth by AASHTO and State agencies. Through the application of these policies, safety is indirectly incorporated into the design process; however, there is not yet a formal, *systematic* method for analyzing the safety implications of particular geometric design configurations. For example, when a designer is considering alternative alignments, the right-of-way and construction costs can be estimated and directly compared. However, the designer has little knowledge about the relative safety effects or expected accident experience associated with the different alternatives. Frequently, research findings are not presented in a form that is easily useable by the designer. Providing the roadway designer with a tool with which to analyze the safety implications of design decisions would benefit the designer, as well as the ultimate safety of road users.

Recognizing this need to better integrate safety into the design process, the FHWA initiated the development of the Interactive Highway Design Safety Design Model (IHSDM). When fully developed, the IHSDM will be applied by highway designers and transportation engineers to assess the roadway design alternatives in terms of explicit safety-related measures. The IHSDM will also be able to assess alternative designs in terms of driver and vehicle characteristics, and it will check for compliance with current standards and policies. For appropriate implementation into the design process, it is anticipated that the IHSDM will operate as an interactive computer program within the Computer-Aided Design and Drafting (CADD) environment.(1)

With the implementation of the IHSDM, the role and emphasis of safety in highway design will change. Instead of transportation engineers reacting to existing high-accident locations that result after a roadway project is completed, IHSDM will enable its users to identify situations proactively before construction. Certain combinations of geometrics and traffic characteristics that may result in an increased accident risk will be identified, thereby affording highway designers and transportation professionals the opportunity to eliminate potential problems.

CURRENT IHSDM CONCEPT

The history of the development and evolving structure of the IHSDM is documented in an article by Paniati and True, "Interactive Highway Safety Design Model (IHSDM): Designing Highways with Safety in Mind."(2) Figure 1 shows each of the primary components, or modules, of IHSDM, as currently conceived. The IHSDM is still under development and its functions and formats are still changing. Basic principles for implementation of the IHSDM were developed so that the system can be successfully integrated into the design process.

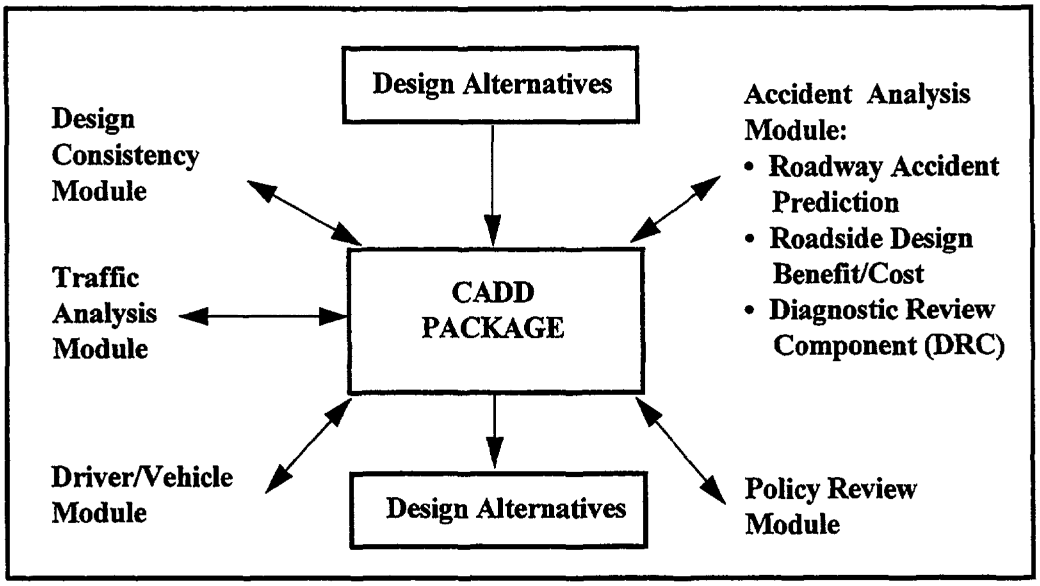


Figure 1. Current structure of IHSDM.

These principles state that the IHSDM must:

- Be applicable for new construction projects and reconstruction projects.
- Facilitate decisionmaking, from planning through the final stages of design.
- Be a computer-based system for operation within a CADD environment.
- Consolidate safety research into a form usable by the designer.
- Be developed in a modular fashion that allows the model to be tested and implemented in phases.[2]

To maintain these principles, the current vision for the IHSDM includes the following five modules:

- Driver/Vehicle Module.
- Design Consistency Module.
- Traffic Analysis Module.
- Policy Review Module.
- Accident Analysis Module.

These constitute the five basic tools that can be applied by the designer and can function with commercially available CADD/civil design software. A brief explanation of each follows.

Driver/Vehicle Module

The Driver/Vehicle Module will allow the designer to "drive" any of the American Association of State Highway and Transportation Officials (AASHTO) design vehicles along various design alternatives, under different control strategies, for a range of driver types. The user will be able to "experience the road" through a three-dimensional computer rendering of the design. For a given vehicle type and speed, the impacts of design elements, such as ramp geometry and passing lane availability, can be evaluated. Various driver profiles will be analyzed in combination with the design vehicle types, to examine the influence of the design on the driver.(2) It is through the IHSDM framework that the FHWA has chosen to place its initial research emphasis on this dynamic visualization of highway geometry and design.(3)

In addition, the Driver/Vehicle Module will consist of a Driver Performance Model linked to a Vehicle Dynamics Model. The Driver Performance Model will estimate drivers' speed and path choices along the roadway, and these estimates will be input to the Vehicle Dynamics Model. The Vehicle Dynamics Model will then estimate the lateral acceleration, friction demand, and rolling moment. Locations within the design that could result in loss of vehicle control through skidding or rollover will be identified.(4)

Design Consistency Module

This tool is intended to evaluate the consistency of a proposed design by using speed profile models that estimate operating speeds at each point along the design alternative and possibly utilize driver workload models. In this way, driver expectancy will be directly assessed in the design process, and problem locations related to design elements will be flagged. Potential consistency problems include: large differences between the assumed design speed and estimated operating speed, and large changes in operating speeds between successive alignment elements. Eventually, the Design Consistency Module may be augmented to consider different vehicle types, a feature similar to the functions found in the Driver/Vehicle Module.

Traffic Analysis Module

The purpose of the Traffic Analysis Module is to estimate the impacts of current and future traffic flows on a given design. Traffic simulation models will be used to assess these impacts. The roadway data will be extracted directly from a CADD environment and, with the appropriate traffic data inputs, simulations will be executed. The Traffic Analysis Module will also provide information on travel time, delay, interaction effects between vehicles, traffic conflicts and other surrogate safety measures. Through simulation, the designer will also be able to identify potential design-related problems that could occur for anticipated traffic conditions, such as a need for more passing zones on different alignments. It is anticipated that the extensive research already conducted by the FHWA into traffic simulation model development will serve as the core of this module. FHWA has already begun refinement and enhancement of a two-lane rural-road simulation model, TWOPAS. This model is microscopic in nature and contains car-following and passing-maneuver logic that is applicable to a range of two-lane rural-road alignments.[2]

Policy Review Module

The Policy Review Module (PRM) will serve as a policy check to ensure that a highway design is in compliance with established AASHTO and State highway design standards. This process will be automated (in CADD) and the program will flag design elements that are not in compliance with the applicable policy for a given roadway functional class and design speed. The module would also provide an explanation of the policy that has been violated. This formalized review will allow the designer to document explicitly the justification for noncompliant situations where it is not cost-effective to meet the corresponding design standards (i.e., design exceptions).

There are certain AASHTO design guidelines that are quantitative, such as minimum degree of curvature, maximum percent grade. Developers of the Policy Review Module intend to include these quantitative rules in the design assessment. Other guidelines in AASHTO's *A Policy on Geometric Design of Highways and Streets* (henceforth known as the *AASHTO Green Book*), however, are qualitative in that they do not contain explicit design values or minimum/maximum numerical criteria. For the current IHSDM vision, qualitative guidelines are not to be included in the Policy Review Module.[5]

Accident Analysis Module

The objective of the Accident Analysis Module (AAM) is to provide the designer with qualitative and quantitative means by which to assess the safety implications and accident expectancy of design alternatives.[2] It is anticipated that this tool may take the form of a separate computer program for use in the preliminary design stage. The program would query the designer for critical input (basic design characteristics) and then provide the designer and/or decisionmakers with expected accident frequencies under the given conditions. In this way, design decisions that influence safety can be made at the earliest stages in the process, with the benefit of having knowledge about the likely safety implications. In the final design phase, the engineer will use combinations of quantitative programs and diagnostic measures within a CADD-compatible environment to analyze the safety impacts of more detailed design characteristics.

The current vision for the AAM contains the following three components:

- Models that estimate the number and severity of expected accidents on specified road segments and intersections within a design alternative.

- A benefit/cost analysis tool to evaluate alternative roadside designs.

- The Diagnostic Review Component (DRC), also referred to as the Diagnostic Review Expert System (DRES), which will use an expert systems approach to evaluate intersection design alternatives, identify geometric deficiencies that may impact safety, and suggest improvements to correct these deficiencies.

These components will work together to assess the safety of a design fully, from both a qualitative and quantitative viewpoint. The first two components will incorporate findings from ongoing research on roadway and intersection accident-prediction models, roadside encroachment models, and benefit/cost analysis techniques. Over the years, various research efforts have attempted to develop accident prediction models, but very few have provided results useful to the designer. By initiating the research needed for this module in IHSDM, findings can be compiled so that the results are consistently and appropriately applied for explicit use from the design side.[(2)]

The third component of the AAM, the Diagnostic Review Component, is the focus of this particular research effort and is described in detail in the following section.

DIAGNOSTIC REVIEW COMPONENT (DRC)

Prior research into accident prediction and vehicle encroachment models has demonstrated the difficulties in thoroughly evaluating the safety of a design using a quantitative analysis. Existing research contains limited insight into causal relationships between geometric design elements and accidents, for two reasons. First, most existing accident prediction models employ only three or four design variables. Outside this small set of variables are many other variables that were judged to have little effect on accidents and little statistical significance.[(6)] Second, the quality of the models is somewhat questionable in terms of accuracy. These prediction models utilize the coefficient of determination, R^2, as a descriptive measure of the adequacy of the model. Past models have yielded relatively low R^2 values, indicating an unsatisfactory degree of variation in the data explained by the model. This has been a source of concern and mistrust by traffic engineers.[(7)] In general, accident data base investigations and statistical predictive modeling efforts have determined that accidents are not very sensitive to individual design elements, making it difficult to rely on these models alone for correlations between geometrics and safety.[(8)]

Current Concepts for the DRC

Although accident and roadway data bases are continually being improved upon and updated, there is much to be gained from embracing the knowledge realized from design experiences. Consequently, the concept of the Diagnostic Review Component (DRC) was founded to provide a package of information and knowledge that is not necessarily based on statistical analyses of aggregated accident data. The DRC will capture the safety and design experience of transportation specialists under one umbrella of knowledge, thus allowing less experienced professionals to utilize and apply expert information in their decisionmaking and design processes. In its ultimate state of development, the module could have the following two capabilities:

- A qualitative tool that functions as an "interactive checklist." The system would incorporate a series of interactive questions to remind the user to check certain aspects of the proposed design, aspects related to one or a combination of design elements that may have been overlooked. Illustrative questions include, "Is a right-turn lane needed at this intersection?" or "Are the corner radii adequate to accommodate heavy trucks?"

- A quantitative tool that performs an automated review. This tool would be applied to the review of a highway design plan within the CADD environment in order to identify or "flag" potential safety-deficient locations.

An expert systems approach would be employed to develop either capability within the DRC. It is important to understand that these capabilities are distinctly different. The interactive checklist is a qualitative system, serving primarily to remind the user of design considerations that may have been overlooked. The checklist may be needed for certain situations where the program cannot properly import, interpret, and utilize the necessary data from the CADD file. If the program can utilize the CADD-based data, then it may be possible for the program to initiate the interactive checklist for a selected feature. For example, it may be possible for an expert system to "recognize" intersections from the CADD file. Then, the program can pose specific questions to users about the design of a specific intersection. However, the user should not be prompted with intersection-related questions if there are no intersections within the project limits.

The automated review capability, which would involve the review of a design plan and the identification of safety-deficient locations, must have a quantitative basis, since the alignment must be described in CADD as a set of points with x, y, and z coordinates. In this case, the system must have numerical guidelines that allow it to analytically distinguish undesirable design situations in geometric design units of measurement (e.g., degree of curvature, superelevation, percent grade). The automatic review capability is much more ambitious than the interactive checklist capability and therefore receives greater emphasis in subsequent sections of this report. Further references to the DRC encompass both capabilities; where necessary, a distinction is made between the interactive checklist and automated review functions.

The Need for a DRC

Despite the development of improved prediction models for the first two components of the AAM, there is still a need for a design review of possible "hazardous scenarios" such as that proposed for the DRC. For example, AASHTO's *A Policy on Geometric Design of Highways and Streets* contains criteria for very specific, individual design elements (e.g., the maximum allowable grade, the minimum length of vertical curve connecting segments with different grades, the maximum degree of curve for a horizontal curve).[9] However, physical situations exist in which all these criteria are met, but when designed in combination with one another, they present potentially dangerous conditions for the driver. For example, consider a design where a very long "steep" downgrade is followed by a "sharp" horizontal curve. While this is not necessarily a desirable design, it may still meet the individual criteria for horizontal and vertical alignment. These types of guidelines need to be incorporated directly into the design process to prevent the inclusion of potentially unsafe configurations.

There are other guidelines that are not necessarily steadfast standards by which a designer is bound; rather, they are presented as "recommended" by the geometric design community. Such safety-related guidelines should also be included in the DRC. In this manner, the DRC is somewhat related to the Policy Review Module in that both are attempting to identify "unsafe" design elements. The DRC, however, complements the Policy Review Module by augmenting the guidance provided by design manuals with "rules of thumb" based on expert opinion and empirical findings from highway safety research or accident investigations.

Currently, many hazardous scenarios are identified only after the roadway project has been constructed and is open to traffic. Usually, an engineer is notified of a high-accident location, and an investigation is made into how to remedy the safety problem, possibly through geometric design modifications. If the geometric, traffic, or roadside elements that contributed to crashes at these locations were documented along with other known, potentially dangerous situations, a knowledge base would begin to form. This knowledge would be designed as a dynamic set of information that can be updated as more discoveries provide additional insights into causal relationships between safety and design. This would allow designers to make more informed and better decisions, which might result in the elimination of a safety problem before it is allowed to manifest itself as a high-accident location.

The DRC is the most recent addition to the IHSDM, and its development is at the conceptual stage. It is the aim of this research effort to determine the most suitable methodology for building the knowledge base. It is important to note that as more information is uncovered, the structure of the module and the methodology for gathering the information for the knowledge base may undergo further changes. Potential modifications to the DRC are described further in the last section of this chapter. Employing a systematic process to develop the knowledge base, however, will benefit the module to the greatest extent, as it will then have the most appropriate information from which to base its analysis. The resulting software will provide the designer with the wisdom of numerous years of design and safety experience. Once fully developed and implemented, the DRC will be the supplementary tool that gives IHSDM a capability that accident prediction models alone could not provide.

Intended Functions and Limitations of the DRC

The DRC will serve to complement the role of senior highway designers in State transportation agencies and design firms who review proposed highway design plans. It is important to note that this expert system will not replace the senior-level design review. Rather, it will enhance the process by providing a more accessible base of knowledge upon which to make informed design judgments. Personnel will still be required to maintain quality control and quality assurance. Also, under many conditions, right-of-way, environmental, or cost constraints may prohibit the designer from making changes for the sake of safety. The DRC can provide guidance on the desirable design situation, but engineering judgment will always be required to determine the most feasible and suitable design situation. It is not the intention of the DRC to be prescriptive or to mandate the implementation of specific actions. The development of the DRC will not remove the design creativity or decisionmaking from the hands of the engineer or designer. Rather, it will provide another instrument with which the designer can assess the safety of the design. The addition of this tool to the design process will give designers an enhanced body of knowledge, making their decisions more informed.

The DRC will be developed so that it can be applied at both the preliminary design and final design phases. In the preliminary stages of a project, limited design information is available. However, it is envisioned that the DRC could perform an initial safety review using data for the design elements known at that stage. As additional design parameters are specified and as the design becomes more detailed, it is envisioned that the DRC will be able to perform a more comprehensive review. At the latter stages of design, combinations of design elements will be explicitly considered by the program. Consequently, it is envisioned that the DRC will complement the Policy Review Module. After the Policy Review Module is applied, the DRC can be employed to identify more subtle design deficiencies and potentially hazardous combinations of design elements.

As discussed earlier, two visions for the DRC have emerged. One vision calls for the DRC expert system to be something analogous to an interactive checklist that would prompt the IHSDM user to enter data or respond to questions about the design. In this vision, the expert system would be primarily qualitative in nature, although it may employ some quantitative rules. It is expected that many items of the interactive checklist will be questions that do not require a quantitative response. In fact, the initial versions of this expert system may require the user to make value judgments about certain aspects of the design, rather than comparing responses with a set of numerical look-up tables. For example, the system may prompt the designer to check the length of a left-turn lane. Alternatively, the program may ask the designer to determine if an intersection design without left-turn or bypass lanes is adequate, or if bypass lanes are necessary. A third example would have the expert system ask the designer to determine if a proposed intersection design featuring a bypass lane is adequate. Currently, there are no accepted application guidelines for deciding when a bypass lane should or should not be implemented. Neither are there guidelines for when extenuating circumstances, such as high average operating speeds and/or a high percentage of trucks, render a bypass lane design unacceptable. Because there are no currently accepted quantitative guidelines that can be embedded in the program, the IHSDM user will need to make the judgment as to whether the bypass lane is acceptable.

It should be clearly understood that this vision for the DRC expert system does not require it to flag explicit problem locations automatically. However, the expert system could identify potential safety deficiencies, based on responses to questions on the interactive checklist. It is expected that for some situations, the expert system will require the user to make value judgments. This is a potential problem with any checklist. All users can be asked the same questions based on the input data. However, the range of responses to qualitative questions depends greatly on the skills, capabilities, and experience of the user. This will be one of the greatest challenges for the expert system development team. Checklist items that are written only as issues to be considered, without providing guidance on what caused a design feature to become problematic, will have little value within the DRC expert system.

For the interactive checklist, it will not be necessary for the expert system to recognize specific situations automatically from a CADD file, although this would be highly desirable and will probably be integrated into later versions. The term "automatically recognize" is meant to convey that the program can identify specific features within a plan and profile CADD drawing. For example, the system finds an intersection within the design alternative and then initiates the interactive process by asking the user pointed questions about that particular intersection. It is currently envisioned that the user (not the program) will initiate this process by indicating the desire to evaluate a given intersection. The expert system would then ask for specific data related to that intersection, such as the station number that corresponds to the point of intersection, projected ADTs for each leg, projected design hour turn movements for each approach, and other elements. It is envisioned that in order to satisfy one of the requirements established for all components of the IHSDM, this expert system must operate within the CADD environment. Thus, it is highly desirable that the interactive checklist be able to extract a maximum amount of data available from the CADD file so that the user does not have to reenter the data. During its infancy, however, the expert system may only have the capability of extracting vertical and horizontal alignment data. The remainder of the required data will be entered by the user.

The second vision calls for the DRC to be something analogous to a fully automated review procedure that would extract and interpret resident data from the CADD file. The program would then display "flags" (e.g., icons) on the computer screen at the approximate locations in the design plan where preestablished rules have been violated. These rules would be written using explicit geometric threshold values that define potentially safety-deficient situations. For this view, the DRC would act as a type of "magnifying glass" that automatically moves along the design plan and compares the design parameters against a set of look-up tables that define specific safety-deficient locations. When the combination of geometric values exceeds the threshold set of values for a given situation, a flag would be displayed.

The degree to which the DRC will affect design is a function of the information contained in the knowledge base. It is not desirable for the automated review to flag elements too often, or for that matter, not often enough. Neither is it desirable for the interactive checklist to require many value judgments by the user. The initial knowledge base will be somewhat limited, and the original version may seem almost rudimentary. This initial model will provide a building block or foundation. With time and increased use, however, the knowledge base will grow. As more designers work with the model and further research is conducted, greater understanding of the safety/design relationship will be achieved. The DRC knowledge base will build on this understanding.

It is important for the potential user to understand that the DRC expert system will not generate estimates of accidents. In fact, the DRC will not generate a single measure of effectiveness applicable to the overall design alternative. In this sense, its use as a comparative tool is limited. Consider that FHWA plans to develop accident prediction models as part of the IHSDM accident analysis module. In the ideal world, these models could be applied to generate estimates of annual accidents, by severity, for each alternative to which they are applied. As an example, consider two design alternatives for improving an existing two-lane rural highway from point A to point B. Assume that one alternative would feature the realignment of several sharp curves on a new alignment, while the other would feature reconstruction on the existing alignment. Accident prediction models could be applied to generate estimates of the expected number of accidents. Using accident unit-cost data, the expected numbers of accidents, by severity, could be converted into accident costs. Then the accident cost values estimated for the two alternatives could be compared directly. Thus, the accident prediction models could be viewed as tools that allow two or more alternatives to be compared directly.

The DRC expert system, however, will not generate single values that are applicable to entire design alternatives. Neither will it generate quantitative measures of effectiveness for a specific alternative or a specific intersection design. Thus, unlike the accident prediction models, the DRC expert system will not allow a direct comparison of quantitative measures of effectiveness among design alternatives. The program will certainly play a role in comparing and assessing aspects of a given design; however, it will not produce quantitative measures that are commonly used in comparative summaries of alternatives. Illustrative measures include acres of wetland disturbed, right-of-way costs, construction costs, number of housing units displaced, predicted improvements in peak hour speeds, predicted reductions in delay and emissions, and changes in annual vehicle operating costs. For example, if one alternative design results in three problem location flags when the DRC is applied, and another alternative produces six flags, the alternative design with six safety-deficient locations identified is not necessarily less safe than the alternative with three. In other words, the number of flags marked by the system is not an indication that one design is superior to the other. This is so because the deficiencies flagged by the DRC are not meant to be ranked or given a weighted value upon which a comparison would be made. Furthermore, a flagged design element or combination of elements does not denote a fatal flaw in the design. Instead, it suggests to the designer that a particular scenario could be safety deficient. However, the flags could be used along with other information, such as cost and traffic effects, to facilitate a comparison of alternatives.

Before concluding a functional description of the DRC, we should recognize that other possibilities exist for the DRC. One alternative view calls for the DRC expert system to provide information on what would be expected in terms of accidents, given the expected traffic volumes, traffic control devices, and geometric design. This information could be obtained from an analysis of the safety and operational performance of existing intersections. This alternative view for the DRC appears to be similar to the roadway accident-prediction models. Given that the Accident Analysis Module for the IHSDM is still evolving, it is difficult to state with any certainty what will ultimately be included in the prototype. It may be that the accident prediction models do not account for many key features, such as traffic control or selected intersection geometric attributes, in which case there may be a need to include accident data in the DRC expert system. However, the DRC should not duplicate the role performed by the accident prediction component. In summary, for this report at this point in time, it is assumed that the function of generating estimates of accidents will be contained in the accident prediction component and not the DRC expert system component.

Alternative Modular Structure for the IHSDM

During the course of this study, it was necessary to explain the IHSDM and the Diagnostic Review Component of the Accident Analysis Module to many transportation professionals who were unfamiliar with the concept. Confusion arose over the connotation of the word "diagnostic," which implies a tool that would help designers diagnose the causes of specific accidents or specific deficiencies at high-accident location sites. The term "diagnostic" lends itself to this inference in that it is defined as determining the nature of an existing problem by examination or analysis.[10] However, the intent of the DRC is not to determine the cause of an existing design problem, but rather to help identify potential problem locations on a roadway design alternative. Further, the objective is to prevent accidents, not to diagnose an existing accident pattern or frequency.

In addition, there is a marked difference between the roadway and roadside accident-prediction models and the DRC of the Accident Analysis Module. While both, to some degree, have a crash-related basis, the accident prediction models yield estimates that can be used as a basis for comparison. As discussed in the previous section, the DRC does not produce values that would allow direct comparison among design alternatives at the project planning, preliminary design, or final design phases. Thus, placing the DRC within the AAM may not be appropriate. For these two reasons, an alternative classification of the DRC may warrant consideration.

When the IHSDM was originally proposed, it was intended to include an Accident Prediction Module, which would consist of a series of accident prediction models for roadway sections, intersections, ramps, and the roadside. At a June 1995 workshop sponsored by the FHWA, many attendees argued that this was an inappropriate methodology for incorporating safety into the design review process. The assertion was that design decisions should not be based solely on accident prediction. Some argued that accident prediction models reflect only gross aggregate statistics derived from a broad sample. Moreover, regression-limited accident prediction models account for four, or at best five, explanatory variables. It was rightfully argued that much could be gained from "cause and effect" relationships determined from diagnostic/forensic reviews of specific accidents and accident sites.[8]

At the time this report was prepared, the decision had been made to develop the Policy Review Module utilizing only design guidelines that were directly quantified in the *AASHTO Green Book*.[9] For example, these include maximum percent grade, minimum degree of curvature, and minimum length of crest for vertical curves. The underlying premise was that software could be developed to compare a given design alternative analytically against the quantitative design guidelines. However, the *AASHTO Green Book* contains many additional guidelines that are not expressed in quantitative terms. Consider the section on design controls for horizontal and vertical alignment coordination. In this section, AASHTO illustrates examples of "poor and good practice," with a general description of how a designer might go about reviewing the horizontal and vertical alignments to identify these poor design scenarios. One example of a deficient design combination, shown in figure 2, is a short tangent on a crest between two horizontal curves. There are no numerical values associated with this geometric deficiency, and there exists no standard that requires this situation to be avoided. The combination is labeled as "poor design." Incorporation of this guideline and automation of this problem identification within the IHSDM would benefit the safety of the roadway. However, because the guideline is nonquantifiable at this time, there are no plans to include it in the Policy Review Module. This leaves an information gap in the safety review of designs. Thus, areas within the *AASHTO Green Book* need quantification if they are to be incorporated within the IHSDM.

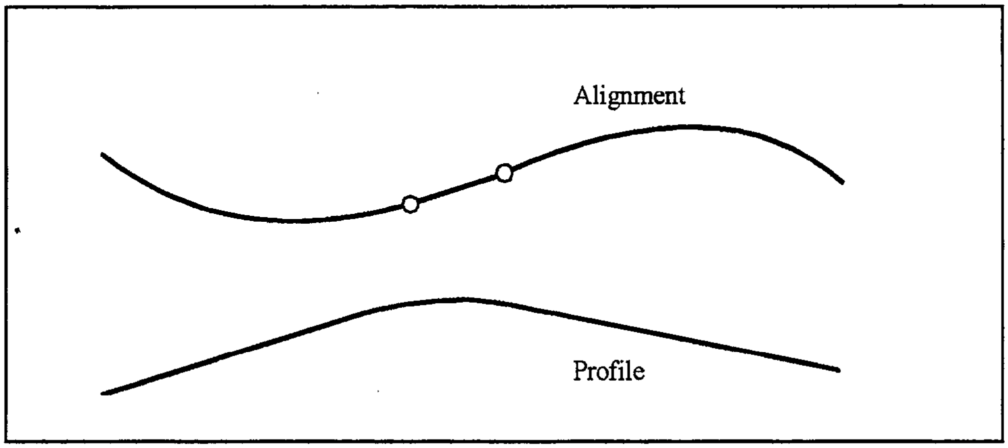


Figure 2. Short tangent on a crest between two horizontal curves.[9]

It is possible that these situations can be translated into quantitative guidelines to be used in an expert system. The process to develop the guidelines could employ one of the knowledge acquisition methods described in this report. The objective would be to translate AASHTO's descriptions of "poor design" into quantitative terms. This effort would require the development of design specifications that explicitly define poor design situations. These specifications, however, cannot be considered AASHTO policy, and should therefore not be included in the Policy Review Module.

A similar approach is possible for quantifying other poor design situations not described in the *AASHTO Green Book*. Both Mason and King proposed procedures to employ a diagnostic approach to an accident analysis module that would flag high-accident problems.[11-12] Another approach would be to extract similar knowledge from experts, including those senior designers who have many years of experience related to the design of two-lane rural-road improvement projects on new and existing alignments. From interviews with these experts, knowledge can be gathered about specific combinations of geometric features and elements that have resulted in accident problems.

The alternative vision of the DRC is consistent with its conceptual function: a tool to review design plans and identify design flaws and potential safety deficiencies. While phrases and terms often have subtle connotations, the DRC was envisioned to be a design review tool, similar to the Policy Review Module. The term "design review," in this context, is not meant to convey the formal process that is typically performed at the end of the design process when all the decisions have been made. It is not the final review performed when right-of-way or construction plans are signed off by chief engineers and individuals with the authority to approve plans. While it certainly could be applied at that time in the design process, it is envisioned that the DRC can be applied at any point in the design process, as long as the design has been prepared within a CADD environment.

Therefore, it is proposed that a new module of IHSDM be created to contain the nonquantitative design guidelines in the *AASHTO Green Book* and those guidelines developed for the DRC knowledge base. Because the module would have an empirical basis (i.e., based on research, observation, accident investigations, or the professional opinions of experts), an appropriate definition would be the Empirical Review Module (ERM). This is consistent with the expert systems approach to incorporate the knowledge of experts into an automated analysis tool. Thus, the DRC, as currently conceived, would be separated from the Accident Analysis Module, would incorporate nonquantitative AASHTO guidelines, and would stand alone as the ERM.

This could lead to less ambiguous titles that could be understood more easily by a larger percentage of the highway design community and the population of IHSDM users. The concept is illustrated in figure 3. The net effect would be to redesignate the modules in the current vision to those in this alternative vision, as shown in figure 4.

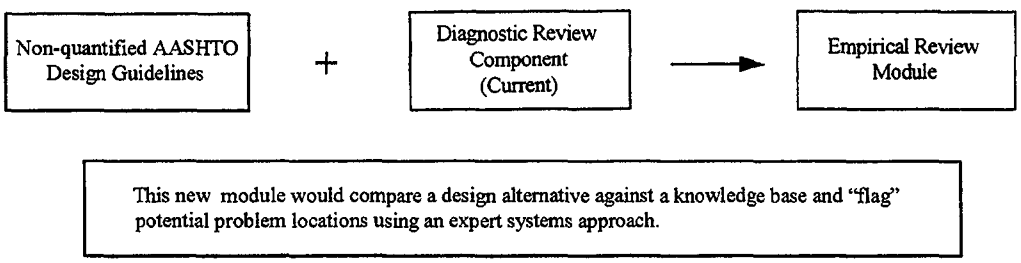


Figure 3. Proposed modifications to IHSDM modular structure.

The sequence for applying these modules would be as follows:

- First, the designer or IHSDM user would apply the Policy Review Module to ensure that all applicable design standards have been met.

- Then, the designer would apply the ERM to review potential areas where certain combinations of geometric features may be safety deficient.

Similar to the Policy Review Module, the ERM would be applicable to all phases of design: project planning, preliminary design, and final design. During the preliminary stages in the design process, known roadway characteristics could include horizontal alignment, vertical profile, number of lanes, ADT, and location of intersections. With these variables in a CADD

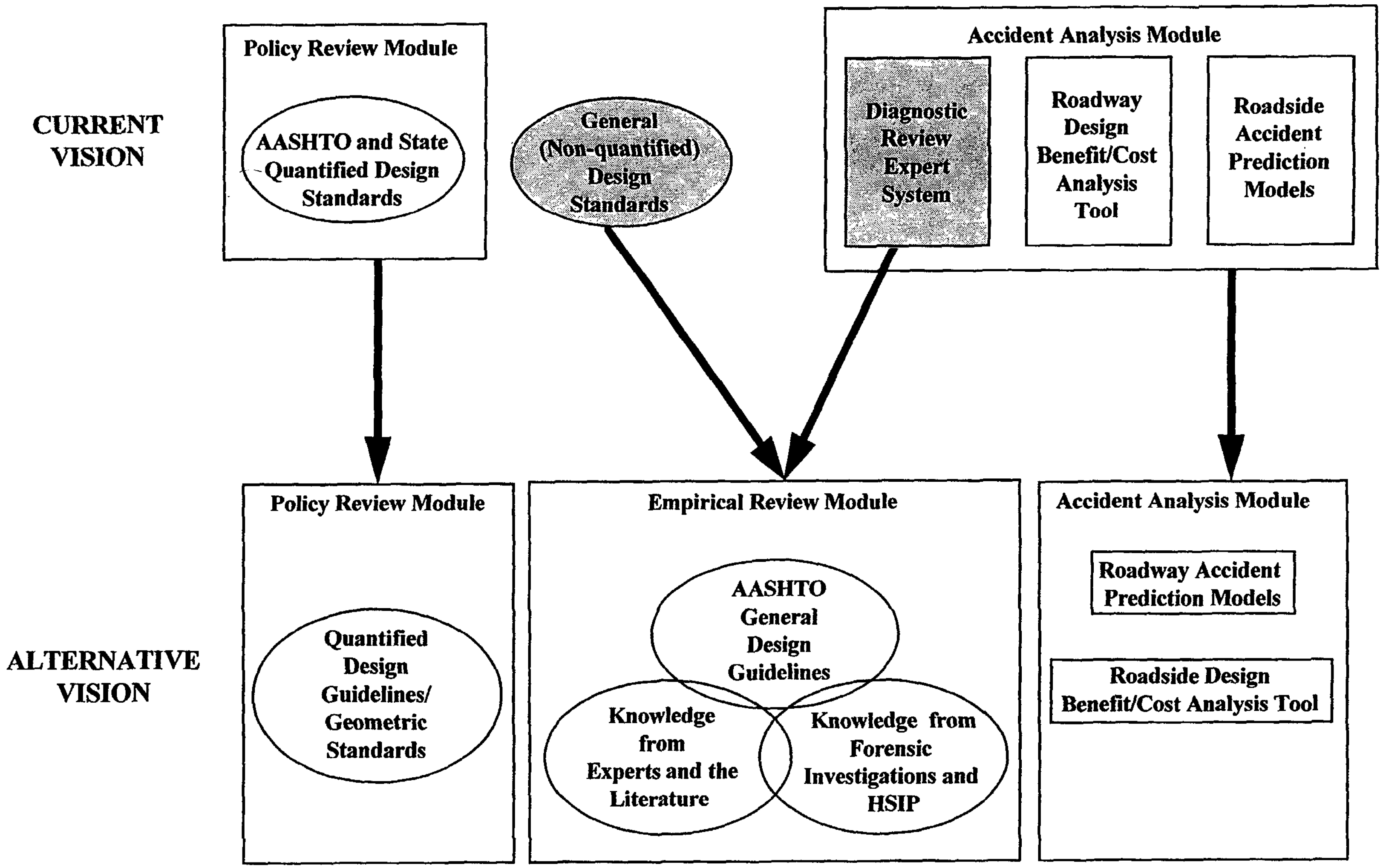


Figure 4. Alternate vision.

environment, even in the crudest form, an initial empirical review could be performed to identify problem locations involving the given elements. As more details of the geometric design are created in the later design stages, the empirical review would be performed again, with the possibility of identifying additional problem locations based on geometric and/or roadside combinations, including the more detailed design elements.

Noting the similarities of the Policy Review Module and the ERM, measures must be taken to avoid potential overlaps between these modules. These tools must be constructed to complement each other, and developers must be careful that the application of the two modules does not produce conflicting or redundant flags. A conflicting flag, for example, could prompt the user to make a design change after running the Policy Review Module. Then, after running the ERM, the location where the design charge was made could be flagged again. Redundant flags will result in users disregarding the utility of the ERM, since it may not appear to offer any additional insight to supplement a policy review. The concerns of redundancy and contradictory messages imply the need for careful coordination between the developers of these modules. Thus, future efforts on both programs should involve close communication between respective contractors and the FHWA to avoid this pitfall. Despite the recommendation that the DRC become the ERM, references to the module in subsequent chapters use "DRC" for consistency.

SUMMARY

This chapter began by discussing the basic objective of IHSDM: to allow designers to incorporate safety into the design process explicitly. The conceptual requirements and modular structure of the IHSDM, as formulated by the FHWA, were introduced. The function of each of the five modules was explained briefly. The concept of the DRC was shown to have resulted from a desire to supplement purely quantitative analyses based on accident prediction models and statistical methods. The DRC is envisioned to have a qualitative feature that functions as an interactive checklist, posing a series of interactive questions to the user. A second, and more complex capability, is a feature that would conduct an automated review of a proposed design and "flag" safety-deficient locations, based on numerical guidelines.

Chapter 2 also discussed the limitations of the Policy Review Module and the potential to incorporate the nonquantified design guidelines into the DRC. The intended uses and limitations of the DRC were discussed, including the perpetual need for engineering judgment, the importance of the knowledge base, and the capability to compare design alternatives. The implications of the term "diagnostic," and the designation of the DRC as a submodule of the AAM, were also discussed. An alternative vision of the DRC was presented. The resulting concept would add an Empirical Review Module and would modify the Policy Review Module and Accident Analysis Module. The need for coordination in the development of the Policy Review Module and the DRC was then noted, to conclude chapter 2.

CHAPTER 3. EXPERT SYSTEMS AND KNOWLEDGE ACQUISITION

The purpose of this chapter is to provide an introduction to expert systems and to discuss different knowledge acquisition methodologies. Although the first two chapters used the terms "expert system" and "knowledge base," this report has yet to explain the general concept of "knowledge engineering," or the available methodologies that could apply to develop the Diagnostic Review Component (DRC). The "knowledge base" is the set of facts and rules that enable an expert system to solve complex problems. Depending on the application, the information comprising the knowledge base may be extracted from subject literature, case studies, one or more human experts, or a combination of these sources. The process of extracting information from the knowledge base is termed "knowledge acquisition." A "knowledge engineer" is the person who is given the task of obtaining such information and translating the data into a computer program. The specific sources of knowledge investigated for the DRC will be discussed separately in subsequent chapters. Much of the information contained in this chapter comes from *Knowledge Acquisition for Expert Systems* and *A Guide for Developing Knowledge-Based Expert Systems.*(13-14)

The first section of this chapter provides an introduction to expert systems and knowledge engineering. The stages of system development are reviewed, with particular emphasis placed on the preliminary phases. The second section is devoted to reviewing different methods of knowledge acquisition and the advantages and disadvantages of each. Feasibility issues and problem areas encountered during knowledge acquisition are also discussed in this section. The knowledge acquisition process for four case studies, with applications to civil and transportation engineering, is reviewed in the third section. The implications for an expert systems approach to the DRC are summarized in the fourth section.

INTRODUCTION TO EXPERT SYSTEMS AND KNOWLEDGE ENGINEERING

Expert systems use heuristics and are data driven (as opposed to procedure driven), distinguishing them from conventional computer programs.(13) Table 1 compares the general characteristics of conventional computer programs and expert systems. A common definition of an expert system is "a program which has a wide base of knowledge in a restricted domain, and uses complex inferential reasoning to perform tasks that a human expert could do."(15) This corresponds to the conceptual function of the DRC: to translate knowledge of geometric design principles and practice into computer-based rules. The DRC has been conceived by the FHWA ". . . as an expert system that could automatically review a potential design and compare it with a "knowledge base" to identify potential safety problems."(2) Thus, the program could review a design alternative within a CADD-compatible environment and identify specific design elements that are potentially problematic. The success of the DRC depends on its ability to pinpoint a similar set of elements as identified by an experienced designer reviewing the same information.

Table 1. Comparison of conventional computer programs and expert systems.[14]

Conventional Program	Expert System
Based on equations that give a correct answer if the numerical input is correct.	Usually based on rules of thumb that are generally reliable, but not always correct.
Provides answers only.	Explains the logic behind the answer.
Input data must be complete.	Input data may be incomplete.
May be developed in isolation from human experts and potential users.	Development team should include human experts and potential users.
Difficult to examine knowledge base (i.e., imbedded equations and logic in the source code).	Provides the capability to inspect the knowledge base.

Expert systems consist of the three main components shown in figure 5. Information in the knowledge base is transferred to the inference mechanism, or problem-solving component, of the system. The input/output interface enables both the user to supply data and the system to ask for more information or provide explanations.[13] The development of the knowledge base is the focus of this research; the remaining two components are not discussed in subsequent sections of this chapter. It is important, however, to have a basic understanding of how the knowledge base relates to other components in expert systems.

The primary advantages of expert systems are:

- Knowledge can be provided in situations where an expert is not accessible.
- The system uses a consistent line of reasoning for different problems.
- The knowledge of multiple experts can be collected in one domain.[13]

The primary disadvantages of expert systems include:

- Knowledge acquisition and representation of the results in the program may be difficult.

- Not all problems can be solved through expert systems, due to complexity, lack of agreement among experts about the correct solution, or a changing nature of the problem.

- Potential users may resist relying on computers for solutions or, conversely, may fail to develop their own expertise due to reliance on the program.

- Testing the completeness and correctness of the program may be time-consuming.[13]

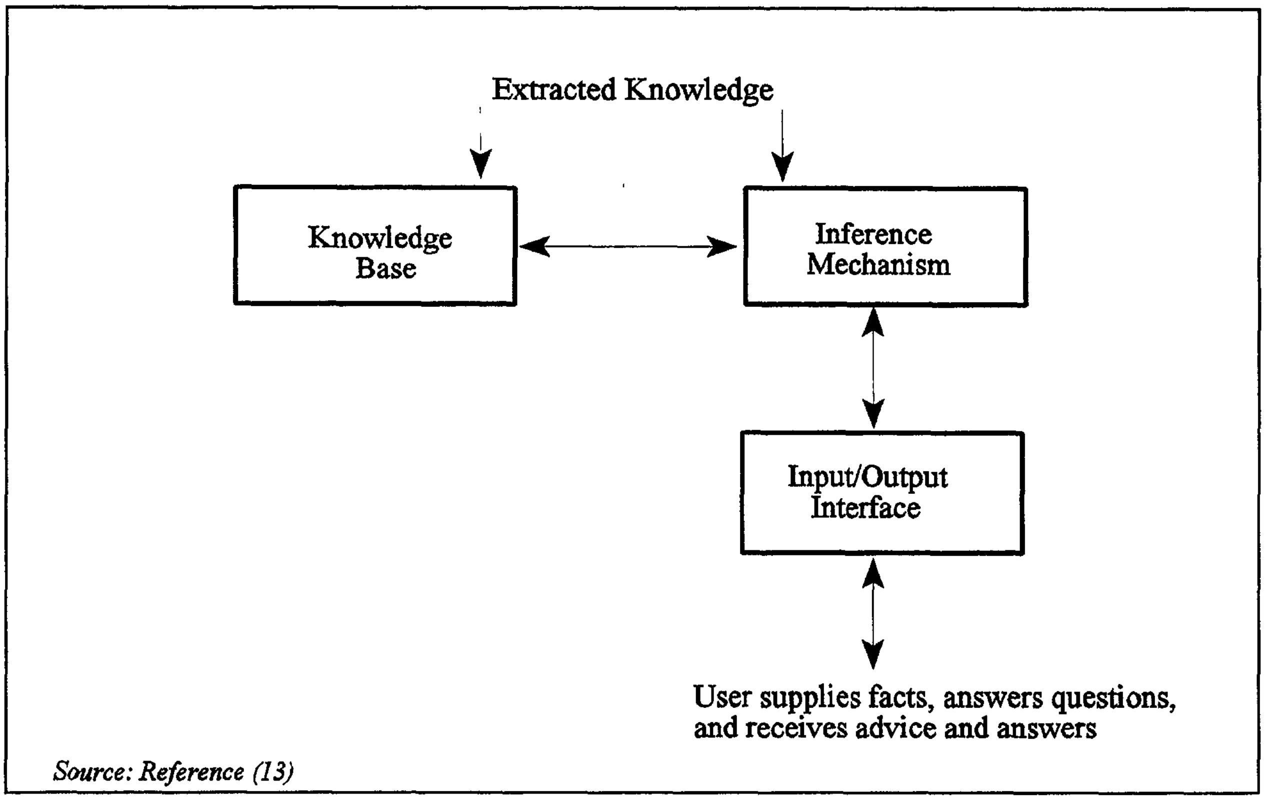


Figure 5. Components of an expert system.

The second bulleted item indicates that an expert system cannot be applied to all situations in which human problem-solving is required. The question then arises, What types of situations are appropriate for expert systems? Wentworth lists five "problem types developed to relate knowledge-based expert systems to roadway applications":

- Diagnosis/Monitoring: A set of symptoms is examined, and a suggested remedy is given.
- Interpretation/Classification: Characteristics of an unknown entity are compared with a known set of conditions.
- Prediction/Forecasting: The future state of a system is predicted, based on a knowledge of past events.
- Design: Specifications of how something is to be built are provided.
- Planning: A series of actions is recommended to attain predefined goals.[13]

The problem types Diagnosis/Monitoring, Prediction/Forecasting, and Design have perhaps the greatest potential application to the IHSDM and thus merit further discussion here. Information concerning Interpretation/Classification and Planning can be found in reference 14.

In Diagnosis/Monitoring, a system's outputs are examined and a remedy is suggested. The goal is to catalogue the symptoms into a specific cause or group of causes and then develop a solution.[14] This type of function could be conceptually applied to the identification of high-accident locations and the development of countermeasures. For example, the user inputs accident data; the system locates the crashes along the alignment; the design features where each crash occurred are analyzed; and the program suggests design improvements at specific locations. This idea has been studied to a limited extent by previous research, resulting in the development of the HISAFE expert system prototype.[15] This program is discussed in greater detail later in the chapter.

Prediction/Forecasting is a determination of the future state of a system, based on the existing conditions and knowledge of past events. The objective is to determine the most likely future results of a set of conditions, along with changes occurring over time.[14] A conceptual example of this problem type is an expert system developed to predict the number, type, and severity of accidents along an existing roadway section, based on historical accident data. Roadway data may include alignment, cross section, roadside hazards, and ADT. The system output is a projection of accident occurrence over a future period of time.

A third type of problem amenable to solution by expert systems is Design. The purpose of this function "is to determine some interconnection of building blocks that will satisfy the constraints of the design." [17] The Policy Review Module of the IHSDM would perform this type of analysis by insuring that the "the proposed design complies with established design criteria." [2] Established design criteria would be taken from the appropriate manuals; thus, no new research is required for this module.[2] The DRC essentially would perform the same type of analysis (checking design elements) based on another set of criteria, which is the knowledge base. The importance of this classification to the process of developing an expert system is further discussed in the next section.

STAGES OF EXPERT SYSTEM DEVELOPMENT

The objective of this section is to review the general process of developing an expert system. For the purposes of this report, the development stages are: (1) identification, (2) knowledge acquisition, (3) design, (4) development and testing, and (5) use.[16] Hypothetical examples using the DRC concept are presented frequently in this section. Emphasis is placed on the identification and knowledge acquisition stages because these elements are the focus of this research effort.

Stage One: Identification

The major tasks in the identification stage are: identify the system objectives (i.e., what will the system be expected to do?), and establish the development team. The development team consists of advocates, knowledge engineers, experts, and users.[14] During the identification stage, the disadvantages of expert systems given in the previous section should also be considered.

To determine whether an expert systems approach should be attempted, consider the following issues:

- Does the problem solving require knowledge that can only be gained through experience and technical tools?
- Are recognized experts available and willing to commit to the knowledge acquisition process? Can the experts reach a consensus?
- What are the costs associated with developing and updating the system?
- Has the scope of the system been accurately defined?
- Who will comprise the development team?[13,14,17]

The general expectations for the system can be defined by first classifying the problem type, as discussed previously.[14] For example, the DRC is expected to perform a design review function by identifying potential safety problems in the design of two-lane rural roads.[2] The knowledge acquired should address such factors as the environment of the roadway and the constraints the design must meet. Expert systems developed for design specify a generic model based on the user's design constraints.[14] For the DRC, the role of the knowledge base is to provide the constraints (e.g., turning radii) based on a set of environmental factors (e.g., average daily traffic, percent trucks).

Development Team

Once these questions have been addressed by the group advocating the creation of an expert system, the next step is to assemble the development team. Team members may be classified into one of four roles: advocate, knowledge engineer, expert, and user.[14]

Advocate

The advocate "champions" the development of the expert system and oversees all related activities. The members of the development team serving as advocates are charged with performing much of the work in the identification stage. Advocates must:

- Identify the need, objective, problem type, and intended user community.
- Define the expected benefits accrued by the users.
- Identify the experts who will participate in the knowledge acquisition process.
- Choose the knowledge engineer who will develop the system.
- Coordinate the entire development process, including future maintenance activities.[17]

The FHWA serves as the advocate for the DRC and the IHSDM overall. For example, the FHWA has funded the development of conceptual plans, coordinated an IHSDM user's group, and funded several studies, with results intended for application to components of the IHSDM. To a lesser extent, a research firm under contract to the FHWA could also serve as an advocate.

Knowledge Engineer

The knowledge engineer is the person who develops the expert system by transforming knowledge into a representative rule-based computer program. This process is called knowledge representation. The result must be as transparent as possible, meaning that the format of the information may change, but not its content.[14] Knowledge representation is discussed later in "Stage 3: Design." The knowledge engineer is also responsible for documenting the development process and testing the results in Stage 3.[14]

Although having an expert serve as the knowledge engineer may seem beneficial, several factors make such a situation undesirable.[13] Experts usually have insufficient programming skills; they have a difficult time adequately describing their own knowledge; and they generally have a poor perception of user needs. Experts should know "enough about expert systems to appreciate the ways in which the system can aid, rather than replace them."[18]

Whatever the knowledge source, the knowledge engineer must have the qualifications to direct the application of the information to the expert system. An understanding of the basic principles and terminology of highway design is a prerequisite to constructing the DRC. Secondly, in contrast to most other expert systems, the DRC is not a stand-alone program. According to the FHWA conceptual requirements, development of the DRC must occur in a CADD-compatible environment. Thus, the knowledge engineer must have extensive understanding of how CADD software operates, how to program in CADD, and how to develop the user interface. Guidance may be provided by those currently constructing the Policy Review Module, due to its similar function. Persons involved in other CADD/expert system efforts may be the most qualified to act as knowledge engineers for the DRC. This research, however, did not investigate other developmental activities for applying expert systems within a CADD environment.

If the knowledge engineer is not the person who programs the software, then he or she must find the most appropriate way to translate the information for those who will. Based on the diverse qualifications listed here, it is likely that the role of knowledge engineer will be assumed by more than one individual. Thus, the role may be filled by a CADD expert, a civil engineer adept in CADD use, and a software developer.

Expert

Expert systems are constructed to analyze information and solve problems, with solutions similar to those given by human experts. Experts may assist in quality control by designing test problems.[14] The definition of human expertise is usually subjective, since the title of "expert" is not given after one satisfies a set of requirements, and conclusions about experts can be made only through personal experience or reputation.[13] Experts can be characterized by the following features:

- Effectiveness: They use their knowledge to solve problems, with an acceptable rate of success.

- Efficiency: They deduce probable solutions and quickly determine the most relevant information.

- Honesty: They will not guess or give inaccurate information.

- Versatility: They perform well in situations outside the ordinary.(13)

Wentworth lists two criteria for the selection of experts: (1) experience in solving problems in the domain of interest, and (2) willingness to spend time for building, testing, and evaluating the system.(14) According to Hart, experts can be used to:

- Provide information by answering questions or presenting hypothetical cases.

- Solve problems with given evidence, identify possible solutions, and determine if given evidence is adequate.

- Explain how the conclusion was reached.(13)

Traffic engineers and designers attain the status of "expert" through involvement in numerous projects over many years. Because of the variety of projects and the extent to which the engineer may be involved, quantifying expert status by a specified number of projects or years of experience would be inadvisable. Due to the large number of experts in the field of road design, some sort of selection process must be employed. Perhaps the only feasible means of identifying experts is their reputation among their peers. Knowledge of the subtle (i.e., beyond what is specified in design manuals) features of "good" highway design is essential. These experts, however, often move into management or administrative positions and may not retain project-level involvement after a certain point in their careers.

User

One of the most frequently asked questions by expert systems consultants is, "What is the actual problem you are trying to solve from the user's point of view?"(13) The key to this question is the realization of the importance of the users' perspective and needs in the development process. The skill level and participation of the users provide valuable information on how the system should be configured to maximize user acceptance.(14) The users also establish how problems are addressed in the field versus the solution prescribed by the expert system during testing. Finally, the users provide a network of individuals to test and promote the system.(14)

Potential users consist of those directly and indirectly applying the IHSDM while preparing design plans for roadway projects. The direct users are the draftspersons or engineers who must be highly competent in CADD software. Indirect users are the engineers responsible for defining the project scope, developing the documentation, and conducting the final review of the plans. Indirect users are those not competent in CADD, but are still responsible for making design decisions. Thus, two distinct types of users should be represented on the development team. The need to incorporate users has been recognized by the FHWA through the formation of the IHSDM Technical Work Group (TWG). The literature stresses the importance of maintaining such an effort throughout the development of the DRC.

Stage Two: Knowledge Acquisition

Knowledge acquisition is the process by which knowledge is extracted from various sources. The process may include several sources of information, such as the literature, research findings, and case studies, although the literature often focuses solely on techniques associated with interviewing human experts. Before the knowledge acquisition process can begin, the knowledge engineer and expert must agree on the conceptual model that will result.[13] The conceptual model forms the basis for applying the information to computer logic. Methodologies of knowledge acquisition and potential sources of knowledge are discussed in greater detail later in this report.

Stage Three: Design

At this stage, a knowledge base of facts and rules has been constructed. Facts are "an assertion that a relation of a set of objects is true."[14] Since the DRC is a design tool, the facts describe the road alignment. For example, two lines drawn on the plans could represent the pavement edge line and the centerline, respectively. Theoretically, the CADD software could be programmed to determine the perpendicular distance between the lines (e.g., lane width). The road alignment is described within the IHSDM critical points data base. The data base contains the set of points wherever a change occurs in horizontal, vertical, or cross-sectional alignment.[19] A rule is an "assertion that some fact is true provided that another set of facts is true."[14] Rules are often written as logical IF-THEN statements. The goal of the knowledge acquisition process is to establish these rules and the variables that govern their application.

Several knowledge representation schemes for translating the facts and rules exist; the choice of a particular scheme should be made by an experienced knowledge engineer.[14] The most common knowledge representation schemes are either rule-based or frame-based. Rule-based representation often consists of condition-action rules (IF-THEN), as described in the last paragraph. Wentworth recommends the use of rule-based schemes where the "knowledge can be represented as a collection of relatively unstructured facts and rules."[14] In frame-based systems, the knowledge is represented by records that could contain design specifications. These records may be linked together so that a single record contains several subfields.[14] For example, a frame entitled "Horizontal Alignment" could include specifications for the radius of curvature and central angle. Subfields might include different specifications for each combination of design speed and average daily traffic. The major advantage of frame-based schemes compared with rule-based schemes is that highly structured knowledge can be placed in logical packages.[14] Knowledge representation schemes for the DRC may include formulas, a plan view sketch, or a table of values similar to those found in the *AASHTO Green Book*.[9]

The remaining tasks in the design stage are the responsibility of the knowledge engineer. They choose the software tools and manage all computer programming. Finally, the knowledge engineer determines when the program is ready for demonstration.

Stage Four: Development and Testing

Activities in the design stage result in an expert system prototype. Hart stresses that "the advantage of a working prototype is that the system can be seen actually running, i.e., in a dynamic state, and the assumptions and definitions which have been elicited can be made public for inspection by a variety of people."[13] The use of a prototype in the knowledge acquisition process is further discussed in the next section. Evolution of the prototype through development and testing can be described by three steps:

- Initial Prototype: Features such as the user interface and explanation facilities are developed. The system is first demonstrated to the intended users.
- Expanded Prototype: The system receives critical analysis from experts and users. This provides the knowledge engineer with areas where the knowledge base or user interface needs refinement. Improvements are then made and at least two additional demonstrations are suggested.
- Delivery System: The delivery system is complete after refinement and final testing.[14]

Throughout the development and testing process, three types of analysis are performed: verification, validation, and evaluation.[14] Verification procedures ask, "Is the system built right?" Validation answers the question, "Is the program doing the job it was intended to do?" Evaluation efforts study user acceptance and the correctness of the system results.

Stage Five: Use

The fifth and final stage of expert system development is distribution and maintenance activities. There are three major criteria for the distribution process:

- Intended users should have been involved since Stage 1. If this has occurred, then the user community will have a vested interest in the testing and application of the system.
- The system should be compatible with standard hardware and software.
- Distribution licenses should be either waived or available at a reasonable fee.[14]

The maintenance task recognizes that the software is never completely finished. There must be a continual process of refinement and improvement, based on new research findings, user participation, and changing user needs.

METHODS OF KNOWLEDGE ACQUISITION

The literature frequently describes knowledge acquisition as the major bottleneck in the development of expert systems.[13,18] The material in this section is devoted to examining various sources of knowledge and reviewing several knowledge acquisition methodologies.

Knowledge Sources

Sources of knowledge are as diverse as the applications for which expert systems are constructed. For some applications, an abundance of relevant literature can be utilized, while for others, little or no published research is of value. Established procedural guidelines and/or standards may be available as a starting point for developing the system. In other situations, protocol or manuals that aid in problem solving may not be relevant. Many experts may be accessible in one case, while for another, only a select few have the desired knowledge.

As discussed in the previous section, prior to the knowledge acquisition process, the knowledge engineer and expert must agree on the conceptual model that will result. Hart provides a series of questions to consider before beginning the knowledge acquisition process.[13] The implications for the DRC are outlined briefly after each issue.

- What are the problems? The identification of potentially problematic geometric design features, or combinations of features, on two-lane rural roads is the focus of this effort.

- What are the solutions? For the interactive checklist, design issues that could be overlooked are identified through a series of questions. For the automated review function, solutions consist of design recommendations in geometric design units of measure that create a threshold to define when a geometric feature (or combination of features) is flagged.

- What types of inputs cause difficulties? Since the DRC will be integrated within CADD software, the automated review will be confined to a quantitative analysis of the relationship between the design elements. A qualitative input, such as a "hidden dip," must be described in quantitative geometric design units of measure for inclusion into the DRC. The interactive checklist, however, is not confined to quantitative inputs only.

- How are the problems characterized? After (or during) the design check by the Policy Review Model (PRM), a similar check is made using the rules developed by experts. Problems are characterized as features that meet the minimum criteria, but that in combination with other factors (e.g., design speed, truck traffic, ADT), are potentially problematic or could be overlooked.

- How are the solutions characterized? Solutions are represented by the pop-up windows or user prompts that describe the specific concern and offer a set of pertinent, qualitative recommendations.

- How are the problems or methods broken down into smaller units?[13] The Policy Review Module groups features according to horizontal alignment, vertical alignment, cross section, intersections, interchanges, and sight distance.[19] A similar grouping could apply to design features analyzed by the DRC.

Knowledge Acquisition Techniques

Although several potential sources of knowledge have been presented here, emphasis on knowledge acquisition techniques is placed with human experts. The primary function of related literature is to familiarize the knowledge engineer with the subject. Depending on the subject area, the literature may also provide part of the knowledge base.[20] There are logical reasons for the focus on extracting human knowledge. The nature of expertise is abstract, and a need frequently exists to augment the information found in the literature. Hart summarizes this point in stating that experts "often make judgments based on intuition. It is more than likely that they have never had to explicitly state how they make such judgments or decisions. The knowledge engineer's routine is much less well defined; hence, a whole new set of difficulties exists in knowledge acquisition."[13] Thus, the emphasis of this section is knowledge acquisition from human experts.

There is a fundamental trade-off in determining the appropriate number of experts to participate in the knowledge acquisition process.[18] Too many experts may produce disagreements that are difficult to reconcile, while the inclusion of too few experts may result in an idiosyncratic system not representative of the overall knowledge. The involvement of multiple experts, however, may generate redundant data that can be used to ensure that the information is reliable. Hoffman states that "disagreements should be used as clues about the basic research that might be needed to fill the knowledge gaps, perhaps before any expert system work can be done."[18] It is the responsibility of the knowledge engineer to blend contradictory statements into a single rule, or to choose only one for use.

The knowledge engineer must choose the appropriate knowledge acquisition technique, based on the given situation. Techniques include: the method of familiar tasks, unstructured and structured interviews, limited information tasks, constrained processing tasks, and the method of tough cases.[13,18,20]

<u>Method of Familiar Tasks</u>

This method is simply observations of the expert performing analyses of typical problems and subsequently developing solutions.[18] The knowledge engineer looks for the type of data that the expert uses to solve the problem and recommend solutions. This method provides data on the decision, but may not lead to a description of how the expert reached the conclusion. The method, however, may be "beneficial because it can give the knowledge engineer a feel for the kinds of knowledge and skill involved in the domain."[18]

Unstructured and Structured Interviews

Interviews with experts may be conducted in a group setting or on an individual basis. The primary advantage of the group setting is potential synergism that can result from several people with different backgrounds focusing on a similar problem. This method "works well if there are significant disagreements to provoke discussion but not severe enough to preclude any agreement."[13] The cost and feasibility of bringing a group of experts together, however, may be prohibitive. Another disadvantage of the group setting is that the process of obtaining a consensus may suppress information.[20] The personality mix within the group may encourage a dominant spokesperson, with others opting to withhold their contradictory views.

Walters recommends a two-on-one interview in which one person asks the questions while the other takes notes or formulates a sketch to represent the knowledge (experts' comments).[20] After a line of questioning is completed, the interviewers switch roles. Experts should prepare for the interviews in the following ways:

- Learn the primary goals of the expert system and understand its importance.
- Consider how they use their expertise to solve similar problems.[20]

Most expert systems use an unstructured interview at some point in the development process. The knowledge engineer asks spontaneous questions while the expert is either performing or describing the task.[18] Questions arise where further clarification is needed, or an example is requested to illustrate the point. In this method, the expert is asked to "think out loud." Unstructured interviews may form the basis for the "first-pass data base" (i.e., the initial knowledge base). Unstructured interviews were completed as part of the investigation into States' HSIP (see chapter 8).

The structured interview combines the unstructured interview and the method of familiar tasks.[18] The knowledge engineer focuses on specific areas in the knowledge base for more detailed information. The expert is asked to review (i.e., debug) systematically the first-pass knowledge base to add/delete entries, qualify entries, reorganize entries, or add/delete categories. The structured interview is similar to prototyping, or building a relatively cheap or simplified model early in the project, to be used as a learning tool for further work.[13] For some experts, criticizing an existing system is much easier than commenting on a hypothetical one. The design of a prototype may take one of three approaches:

- A throw-away prototype is built exclusively as a learning tool and is then discarded after use.

- An incremental prototype is subdivided into mini projects in which the completion of one part leads to the development of another part.

- An evolutionary prototype is continually changing, based on the experts' input.[13]

Limited Information Tasks

In a manner similar to the method of familiar tasks, the expert is observed while engaged in solving typical problems and developing solutions.[18] In this case, however, segments of the information are withheld from the expert. This forces the expert to provide additional evidence of his or her reasoning by describing how the missing data affect the hypothesis. Thus, although they cannot provide a solution, the reason(s) why represent(s) highly useful information. Experts with different backgrounds may be asked to examine the same problem, to learn how the lack of specific information affects the hypothesis.[18]

Constrained Processing Tasks

In constrained processing, the time the expert has to solve the problem may be limited.[18] Another constraint may be imposed by the knowledge engineer asking a specific question, rather than requiring an analysis of the entire problem. Combined constraints involve the expert solving a problem with both limited time and limited information. Similar to the limited information task, this method may be resisted by the expert because it creates an unfamiliar environment compared to that of typical problems.[18]

Method of Tough Cases

It may take a problem with increased difficulty to elicit subtle or refined aspects of the experts' knowledge.[18] The knowledge engineer is not likely to be present, however, when a tough case is encountered by the expert. Tough cases may also be identified intuitively by the expert's recollection of past projects. Information about such projects may be limited to anecdotal information or archived files.[18]

Comparison

Table 2 lists a summary of the advantages and disadvantages of each type of knowledge acquisition method. Some methods are best suited to the initial stages of developing the knowledge base (method of familiar tasks, and unstructured interviews), while others are more applicable once the first pass at the knowledge base has been made. The unstructured interviews can allow the knowledge engineer to determine: (1) who the experts are, (2) whether the problem is well suited to an expert systems approach, and (3) what the users' needs are.[18]

Table 2. Advantages and disadvantages of various methods of knowledge acquisition. [18]

Method	Advantages	Disadvantages
Familiar Tasks	Expert feels comfortable.	Time-consuming.
Unstructured and Structured Interviews	May generate much information for a first- or second-pass knowledge base.	Time-consuming.
Limited Information Task	Can enable knowledge elicitation from selected subdomains.	Expert feels uncomfortable and is hesitant to make judgments.
Constrained Processing Task	Can enable knowledge elicitation from selected subdomains or the experts' strategies.	Expert feels uncomfortable and is hesitant to make judgments.
Analysis of Tough Cases	Can yield information about refined reasoning.	Occur unpredictably, knowledge engineer may not be present.

EXPERT SYSTEMS APPLICATIONS TO TRANSPORTATION ENGINEERING

An expert systems approach to developing software for transportation facilities decisionmaking and design began to surface in the mid-1980s. Program functions included pavement management strategies, noise barrier design, traffic signal timing, and capacity analyses.[15] The basic objectives, data input and output, and knowledge acquisition procedures for four systems are summarized in this section. The systems selected for review in this report do not represent a comprehensive set of applications developed for transportation applications. Case studies were selected to demonstrate various knowledge acquisition techniques that have been previously employed. Information on the systems included here comes from published papers or research reports, some of which are dated. The present-day expert system may represent a vastly improved version over one described several years ago.

HISAFE

The HISAFE program (1988) was developed to perform highway safety analysis by examining both accident data and road conditions.[15] The program has two modes:

- Mode 1 determines possible accident causes, based on the accident type and related factors.
- Mode 2 determines potential accident causes, based on the existing traffic and road conditions.

For mode one, the accident types are first classified into collisions, pedestrian involved, and others. For mode two, the traffic and road conditions are first classified into geometric related, intersections, pavement conditions, and others. For mode one, the system prompts the user, based on the previous response, until it has identified the exact accident type. Similarly, for mode two the system prompts the user until the site characteristics are properly classified. The program recommends one or more countermeasures to mitigate the problem (mode 1), or predicts likely accident patterns based on the site characteristics (mode 2).

The knowledge base for HISAFE is constructed primarily from two sources in the literature:

- *Manual for Analysis, Evaluation and Selection of Highway Safety Improvements in Local Jurisdiction*, R.D. Layton, January 1981.

- *Safety Design and Operational Practices for Streets and Highways*, FHWA, May 1980.

These sources would be supplemented by research results as they became available. The system is rule-based, consisting of logical IF-THEN statements. The knowledge base is designed to allow a high level of flexibility; therefore, a local engineer could customize the program, based on special knowledge of local conditions. Future objectives for HISAFE include developing program features to allow an economic evaluation of the recommended countermeasures.(15) HISAFE is currently available through McTRANS, but has not been updated since June 1987. Sales staff at McTRANS could not report how may people are currently using it or have used it.

VLIMITS

The Road Traffic Authority in the Province of Victoria (Australia) developed VLIMITS (1988) to assist traffic engineers in determining the appropriate speed zone for a section of roadway.(21) Speed zone assessments are based on several factors, including road environment, abutting development, accident history, and adjacent speed zones. Inputs to the system include the environment (urban or rural), section length, cross section, roadside characteristics, and median. The system output is either a speed limit for the section, or recommended modifications to the zone length, or speed limit on adjacent sections.

Knowledge acquisition for VLIMITS consisted of the method of familiar tasks and field studies. Researchers attended two meetings of the Victorian Speed Limits Committee, which at each meeting processes between 20 and 40 applications from local councils requesting speed zone changes. An experts' panel was then convened to view slides of 52 sites and discuss the appropriate speed zone application. Two additional experts' panel meetings were held to decide the factors that influenced the speed zone application and the relative importance of one factor to another. Field measurements were taken at 64 sites to provide data over a wide range of speed zones and road characteristics. The design of the system was intended to allow the user to examine the underlying factors and decision rules, add new examples, identify inconsistencies, and modify the rules, based on additional data. Researchers concluded that VLIMITS should provide the correct speed zone 80 to 90 percent of the time. Upon receiving approval from the Road Traffic Authority, VLIMITS was planned for distribution to traffic engineers in Victoria.(21) It was not determined how many people, if any, were currently using this program in Australia.

PASCON

The New York State Department of Transportation (NYSDOT) developed PASCON (1991) to aid in the design of passive snow control schemes along sections of the roadway.[22] Passive snow control includes drift-free roadway design, snow fences, and shelterbelts (rows of trees or bushes), which offer some control over where wind-driven snow is deposited. The objective of the program is to predict snowdrift profiles created by topographic features and snow fences. Input data include the roadway cross section, climatological data, and regression models that predict drift size. The system estimates the snow drift profile and suggests either no treatment or one of the three passive control designs listed here.

The knowledge base was divided into history of methodologies, current practices in western New York, and global knowledge of the subject. Several sources were tapped to provide information for the PASCON knowledge base, including the literature, U.S. Army Corps of Engineers files, and NYSDOT files. A single expert was identified as the leading authority on passive snow control. State, county, and local officials in New York were also consulted regarding their needs and potential use of the system. Much of the domain knowledge came directly from the expert. Knowledge acquisition consisted of a series of unstructured interviews, structured interviews, and constrained processing tasks. The expert was also involved in the verification efforts, comparing the system recommendations with his own for a location with recurrent snow drift problems. The system and human expert solutions were very close. The PASCON prototype is still under development to allow integration with CADD software and eventual distribution to NYSDOT offices statewide.[22]

OCARD

To assist Ohio Department of Transportation (ODOT) engineers in the proper signing of curves on rural two-lane highways, the ODOT Computer-Aided Road Delineation (OCARD) system (1993) was developed.[23] The goal of the program is to delineate curves with comparable geometry and traffic volumes, in a consistent and uniform way. The recommendations given by the program are based on driver visibility, performance, and safety considerations. Field data entered into the program include the curve's heading change, superelevation, curve length, lane widths, and approach speed. The system output is a plan that denotes the recommended type and location for each sign along the curve.

A survey was conducted to determine the state of the art in curve delineation practice, as well as the information needs of engineers in the United States and Canada. Photologs of curved sections of roadway in two ODOT districts were reviewed to examine the uniformity of applications. An expert's panel of 12 traffic engineers was convened to perform before and after delineation evaluations (method of familiar tasks). From this research, rules and algorithms were developed and programmed.[23] It is not known if OCARD has since been distributed to ODOT districts, and if so, the extent to which it is used.

IMPLICATIONS FOR AN EXPERT SYSTEMS APPROACH TO THE DRC

This chapter has provided a basic introduction to expert systems, the five stages of system development, and various knowledge acquisition techniques. With this understanding, it is necessary to examine the implications of an expert systems approach to the DRC. An expert systems approach is envisioned because the DRC will function as an assistance tool for a task that requires humans to solve complex problems. Based on this definition, criteria for success include:

- The DRC's interactive checklist prompts the user with only relevant and important issues (that an expert designer would consider), based on the design features and roadway characteristics.
- The DRC's automated review identifies a set of deficiencies similar to those that would be identified by a human expert in geometric design or traffic engineering.
- The DRC has the faculty to explain the nature of the deficiency, and it makes useful recommendations.
- The DRC does not significantly increase the cost or time required to complete the design plans.

The primary advantage of the DRC is that knowledge from multiple experts with various backgrounds is allocated into a single program that can be used by novice designers. In addition, the program acts as an interactive checklist, ensuring that numerous items are reviewed each time and subtle deficiencies are consistently flagged. Finally, the DRC provides another medium for the transfer of knowledge from experienced designers, who may be contemplating retirement, to those new in the field.

Perhaps the greatest potential problem facing the DRC is a lack of agreement among experts. Design practice is highly location-specific: designers in one State or region may be reluctant to apply their knowledge to other areas. Other rural areas might be characterized by the local driving population, major development proximity, topography, and climatology. Thus, allowing potential users to inspect and alter the DRC is important (table 1).

Problem types with potential application to the IHSDM were listed as diagnosis/monitoring, prediction/forecasting, and design.(14) By this classification, the DRC is most closely associated with design and not diagnosis/monitoring (see chapter 2). For the automated review feature of the DRC, design criteria must be quantifiable, due to the format of the IHSDM critical points data base describing the alignment.(19)

Within a CADD environment, the DRC will function much like the Policy Review Module (PRM). The key difference is that PRM criteria consist of design standards rather than a knowledge base. A program that analyzes accident data superimposed along an alignment provides a better correlation to a diagnosis/monitoring function. Symptoms include accident type(s), location design features, and environmental factors. The solution consists of suggested contributing factors that relate to design. This distinction was previously made in the "Alternative Vision" section of chapter 2.

The five design stages in expert system development are shown in figure 6. The tasks associated with each stage are listed in parentheses. The DRC is currently at Stage One, with its objectives being defined and the development team not yet complete. The FHWA serves as the advocate. Potential users are included in the IHSDM Technical Work Group, but additional members should be added so that direct and indirect users are represented. The experts and the knowledge engineer will be identified in the next phase of this project. The FHWA should oversee the completion of Stage One before Stage Two begins. An important task of Stage One is to address the feasibility issues raised in this chapter, and to involve potential users so that both the system objectives and the design maximize user acceptance.

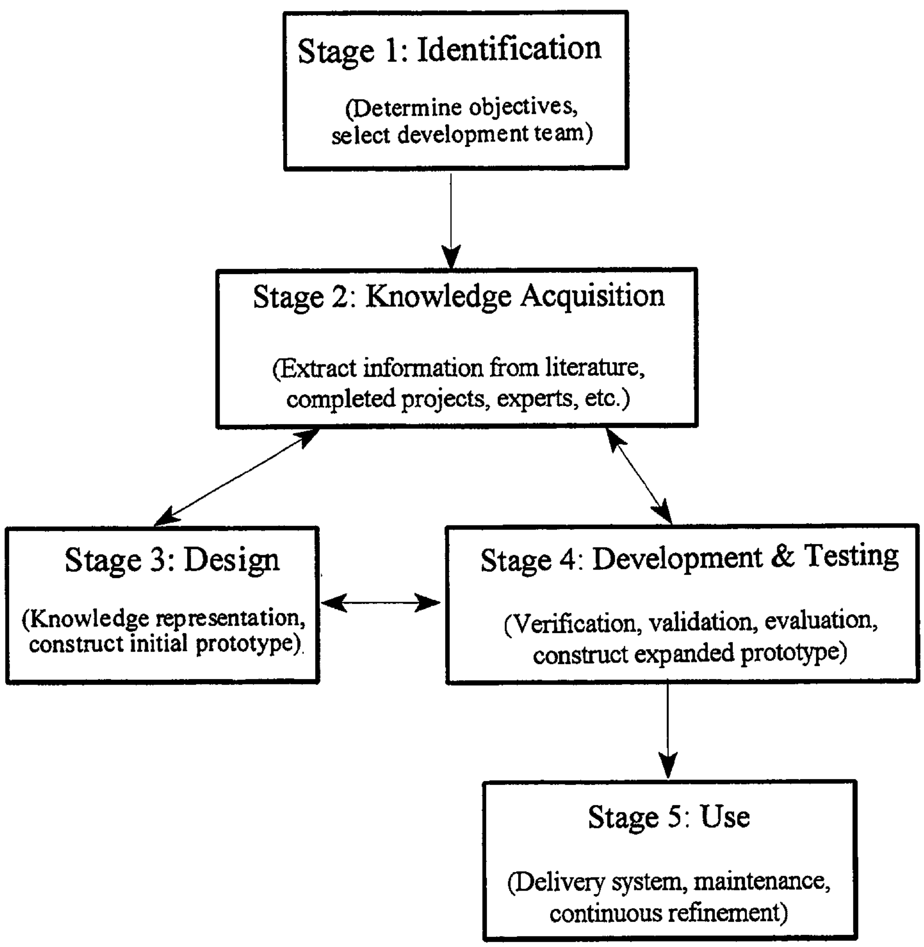


Figure 6. Stages of expert system development.

Stage Two, Knowledge Acquisition, should heavily involve the knowledge engineer. As shown in figure 6, a feedback loop connects Stages Two, Three, and Four. The experts and/or users should be consulted to ensure that the system effectively mimics an experienced designer by flagging the appropriate deficiencies, or prompting the user with the appropriate checklist. Knowledge acquisition is never completely finished. The system undergoes continuous refinement in Stage Five, based on the opinions of users.

While human experts generally contribute to the knowledge base, rarely can they supply the complete set of facts and rules. Therefore, an examination of the knowledge should include all potential sources. The literature should be consulted in the preliminary stages, so that the knowledge engineer has a basic understanding of the problem before the experts are selected.

Knowledge acquisition techniques were classified into five categories: method of familiar tasks, structured and unstructured interviews, limited information tasks, constrained processing tasks, and method of tough cases.(13,18,20) Table 3 lists potential techniques that may be applied to acquire knowledge for the DRC from human experts. The knowledge base should be thought of as a dynamic entity that begins with a rough "first pass," improves with a "second pass," and receives continual refinement throughout the life of the expert system. Thus, different knowledge acquisition techniques should be applied for various passes at the data base.

Table 3. Potential knowledge acquisition techniques for the DRC.

	Knowledge Base Development		
	First Pass	Second Pass	Refined
Method(s)	Literature review	Structured interviews	Prototyping
	Unstructured interviews	Field investigations	Tough cases
	Familiar tasks		

Unstructured interviews with State and local engineers have been conducted in this study (see chapter 8). The objective of the interviews was to generate a first pass at the knowledge base by determining the typical problems, projects completed, and information available. The first-pass data base consists of the specific areas of emphasis identified by traffic engineers as the biggest problems on two-lane rural roads. The next phase of knowledge acquisition must develop: (1) the content of the checklists and the point at which the user is prompted with a given checklist, and (2) quantitative descriptions of these problems. This will allow the knowledge engineer to generate the rules of logic for the automated review feature.

The method of familiar tasks is a third method that could be employed to construct the first-pass knowledge base, especially for the interactive checklist features. The observation of a senior designer's decisions throughout a two-lane rural-road project may provide valuable insight as to the questions asked when design alternatives are being evaluated. A single project, however, takes years to progress from planning to the design phases. Therefore, observing more than a few projects may be difficult. This method could be used to better understand how the DRC (and the IHSDM overall) will be incorporated into a State's or consultant's current procedure for evaluating a road design. Further involvement of the Technical Work Group (TWG) may also provide this type of insight.

In the second pass, structured interviews may be completed to generate quantitative values (e.g., degree of curvature, shoulder width) to describe each area of emphasis defined in the first pass. The structured interviews may be supplemented by multidisciplinary field investigations (discussed in chapter 6), for areas where the knowledge is conflicting or incomplete. These efforts should result in a knowledge base with quantitative rules corresponding to each area of emphasis.

Prototyping was discussed as a form of a structured interview because it forces the expert to criticize aspects of the knowledge base or user interface. Prototyping is optimal for expanding and refining the DRC knowledge base, because of the module-based structure of the IHSDM and its similarity to the PRM, which is already in the design stage. The main advantage of prototyping is that it gives the expert "something to see" and generates ideas for further improvement.

Finally, the DRC knowledge base may be refined through tough cases. As the prototype receives further scrutiny from the users, the checklist questions are refined and the automated review is modified to flag situations not previously encountered or considered. This process is similar to that of conventional programs. User input results in changes to the program, resulting in a new release, or version, of the software.

Table 4 summarizes the knowledge acquisition techniques employed by expert systems developed for transportation applications. Literature on these systems described only the initial stages of development; therefore, these methods were used to develop the first and second passes at the knowledge base. Other methods may have been employed to refine the knowledge base since publication of the research cited in this report. Table 4 indicates the need for multiple sources of knowledge, especially in the early stages.

Table 4. Knowledge acquisition methods used in case studies.

System	Knowledge Acquisition Method(s)
HISAFE	Literature, and research results.
VLIMITS	Method of familiar tasks, experts' panel meetings, field studies.
PASCON	Unstructured and structured interviews with a single expert, research results.
OCARD	Surveys, review of photologs, experts' panel meeting.

SUMMARY

This chapter provides an introduction to expert systems by defining several key terms, describing the basic components, and outlining distinguishing features from conventional programs. The primary advantages and disadvantages are given, along with the five types of problems that are amenable to solution by an expert systems approach. The stages of system development-identification, knowledge acquisition, design, development and testing, and use are each described. The development team, consisting of advocates, knowledge engineers, experts, and users, is discussed. Chapter 3 also compares five types of knowledge acquisition techniques: method of familiar tasks, unstructured and structured interviews, limited information tasks, constrained processing tasks, and method of tough cases. Four expert systems, with applications to transportation, are reviewed to outline the system objectives, knowledge base, and knowledge acquisition methods, respectively. Finally, this chapter discusses the implications of an expert systems approach to the DRC. The five stages of development are reviewed by highlighting the associated tasks necessary to construct the DRC. The concept of multiple passes at the knowledge base in an ongoing effort of refinement is introduced. The knowledge acquisition methods that could be utilized in the experimental plan are then presented, to conclude chapter 3.

CHAPTER 4. THE DRC KNOWLEDGE BASE AND THE EXPERT SYSTEMS APPROACH

This chapter describes the key issues related to the development of a knowledge base for an expert systems approach to the DRC.

PURPOSE OF THE DRC KNOWLEDGE BASE

In order to understand the purpose of the DRC knowledge base, it is important to visualize how the expert system will operate. Although the DRC, like the entire IHSDM, is still evolving, the basic concept is that the DRC will interact with both the user and a CADD-generated design plan. The interactive checklist feature will pose a series of questions to the user, addressing issues that may have been overlooked. The checklist will either be user-prompted, or initiated when specific design features (e.g., curvature, intersections) in the CADD plan are recognized by the expert system program.

The automated review feature will essentially scan the alignment for specific combinations of geometric features and elements that have been defined and stored in a knowledge base. Where a specific combination is found within the CADD drawing, it will show a symbol of a flag at that specific location on the plan view, indicating that a potential geometric design deficiency exists. If the user clicks on the flag, then additional information in the form of a pop-up window will appear. Although the content and format of the information has not yet been determined, it is likely that the pop-up window will describe the problem and identify possible corrective actions to mitigate the potential safety-related design deficiency.

An example of a pop-up window is presented in figure 7. This example shows that the pop-up windows will display predominantly qualitative information and several corrective actions for the user to consider. Thus, the purpose of the knowledge base is to serve as the engine that drives the interactive checklist and the automated review. In essence, it is a body of knowledge, found through empirical means or expert opinion, about combinations of design features and elements that have been found to affect safety adversely.

METHODS FOR DEVELOPING THE DRC KNOWLEDGE BASE

In April 1996, an IHSDM workshop was held at the Turner-Fairbank Highway Research Center in McLean, Virginia. Participants included: experts from State agencies, universities, and private consulting firms; representatives from the Safety Design Division of FHWA's Office of Highway Research; and the contractor team. The objectives of the workshop were to solicit ideas on the DRC, and knowledge about specific situations and combinations of geometric elements and features that have been identified as safety deficient. At that meeting, potential methods for developing the knowledge base were presented, discussed, and debated. The consensus finding was that six alternative methods could be pursued to develop the knowledge base. The six alternative approaches include the following:

- A review of tort liability literature and court cases.
- Interviews with experts.
- Clinical investigations of specific accident sites by multidisciplinary teams.
- A review of accident research and highway safety literature.
- A review of well-designed before/after studies.
- Investigations of highway safety improvement programs.

Problem: **"Sharp left horizontal curve on level grade preceded by a long steep, tangent downgrade."**

Possible Corrective Actions:

- Consider increasing the curve radius/reducing the degree of curvature of the horizontal curve.
- Consider changing the superelevation and spiral transition.
- Consider changing the vertical alignment to achieve a more gradual downgrade.
- Consider widening the pavement on the outside of the horizontal curve.
- Consider flattening the sideslopes on the outside of the curve, increasing the clear zone on the outside of the curve, and/or installing guardrail.
- Consider changing both the vertical and horizontal alignment to reduce the length of the tangent downgrade, reduce the percent downgrade, increase the radius of curvature of the horizontal curve, and/or increase the transition between the downgrade section and the horizontal curve.
- Consider appropriate signs, markings, and delineation.

Figure 7. Illustrative example of a DRC-generated pop-up window.

Table 5 lists each source of knowledge and the corresponding research task for investigating its potential benefit to the IHSDM. The table illustrates the diversity of potential knowledge sources examined by this and other research studies. Expert interviews were conducted both over the telephone and in person to examine the cost-effectiveness and utility of each method. Clinical and forensic investigations were conducted by a multidisciplinary team, which performed field studies at 17 high-accident sites in Minnesota and formed conclusions about potential countermeasures. A review of highway safety improvement programs (HSIP) and telephone interviews with State and local traffic engineers were completed for seven States. The information sought included a description of the types of safety improvements made, and general comments related to high-accident locations on two-lane rural roads.

Table 5. Potential sources of knowledge and corresponding research task(s).

Knowledge Source	Research Task(s)
Tort Liability Cases	Review cases where highway design issues are the basis of tort liability claims. (This work effort was completed by another consultant as part of a separate FHWA contract.)
Expert Interviews	1. Conduct telephone and in-person interviews with experts in crash investigation, human factors, and geometric design. 2. Conduct telephone and in-person interviews with design and safety personnel in State DOT's.
Clinical and Forensic Investigation	Perform field investigations at selected sites in Minnesota, utilizing a multidisciplinary team.
Literature/Published Research	1. Review literature examining the relationship between geometric design features and safety on two-lane rural roads. 2. Review accident research on two-lane rural roads. 3. Review literature pertaining to safety audits.
Design Manuals and Policy Guidelines	(Applies to Policy Review Module of the IHSDM.)
Analysis of Completed Projects	1. Review Highway Safety Improvement Program (HSIP) procedures and documentation. 2. Review well-designed before-and-after studies. (This work effort was being conducted by another consultant under a separate FHWA contract at the time this report was prepared.)

Tort Liability Cases

At the April 1996 experts-panel meeting, the types of literature that may apply to the IHSDM were discussed. A persuasive argument was made by Mason that an important body of literature was missed. This type of literature relates to accident claims. Several "experts" who attended the meeting indicated that at least some States maintain files of all tort liability cases in which the design of the roadway was claimed to contribute to the crash. It was determined by the FHWA that an investigation of these documents should be conducted. This effort was undertaken by another consultant as part of a separate FHWA research contract. The results are documented elsewhere (see reference 24).

Expert Interviews

One of the primary sources of knowledge for the knowledge base was deemed to be expert knowledge from the following, not in any prioritized order:

- Designers.
- Human factors specialists.
- Traffic engineers.
- Accident reconstructionists.
- Law enforcement personnel (to a lesser degree).

Because of the need to develop detailed specifications of problematic situations in geometric design units of measure, the implicit requirement was that all experts to be interviewed have a thorough understanding of highway design.

It is important to understand that expert systems are typically based on knowledge extracted from human experts. Unfortunately, one person's definition of an "expert" may differ from that of another person. To resolve any ambiguities with respect to experts to be used in developing the DRC knowledge base, the following questions need to be answered:

- Who are the experts?
- In what specific areas do they have expertise?
- When, where, and how did they acquire their knowledge?

The interview of experts is discussed in greater detail in chapter 5.

Clinical and Forensic Investigation

It has been proposed by others that this is the most appropriate method for developing the knowledge base. King proposed the use of enhanced police-level accident data, in-depth accident data based on either a bilevel investigation or an on-scene investigation.(12) Mason proposed the use of clinical investigations at accident sites.(25) Mason indicated the following:

> *"The diagnostic approach of forensic engineering, and prudent interpretation of the results, can assist in the identification of the causal factors of an accident.*
>
> *"By determining and analyzing the causal factors of accidents, it is believed that a deeper understanding of the relationships between accidents and geometric design elements can be realized. These relationships can be subsequently used by engineers and designers in the design of new or reconstructed facilities.*
>
> *"This subsequent discussion proposes the use of forensic engineering (via in-depth accident reconstruction and police accident causal analysis as specific tools) to make recommendations to designs of the various geometric design elements of at-grade intersections. The at-grade intersection is used as the*

example because it encompasses most of the critical elements of highway geometric design: intersection sight distance (ISD), horizontal alinement, vertical alinement, cross-section (travel and auxiliary lanes), and location of traffic control devices (TCD)."[25]

To this end, an exploratory effort was conducted in which a three-person team performed site investigations of 17 intersection sites in Minnesota. The results are described in greater detail in chapter 6.

Literature and Published Research

At an early stage in this research effort, the literature review concentrated solely on accident research literature. A heavy emphasis was placed on investigating the findings from highway safety research, including studies conducted under the sponsorship of the FHWA and the National Cooperative Highway Research Program (NCHRP). The focus was limited to literature from the United States and Canada. During this research effort, additional areas of the literature were identified as being potentially useful. These are described briefly here and in greater detail in chapter 7.

Accident Research

Documents that were reviewed included syntheses of safety research related to traffic control and roadway elements, published by the FHWA and other relevant research. Many of the research efforts included attempts at developing relationships between accidents and geometric design features. The literature could be used to identify items that initiate elements of the interactive checklist, or features that should be investigated as potential problem-emphasis areas during the development of the first pass at the knowledge base. Research findings, however, were not specified to a level of detail such that the information could be directly applied to the automated review features of the DRC. Consequently, the literature was reviewed with the objective of identifying generalized problems related to geometric design, which could be applied during the first pass at the knowledge base. The results of that investigation are also discussed in chapter 7.

Driver Performance

In addition to accident research, literature related to driver performance was identified as a possible knowledge source for the knowledge base. It was thought that specific geometric problems could be identified through a better understanding of how drivers perform on two-lane rural roads. Again, the explicit specification of the problem situations, expressed in geometric design units of measure, could not be extracted from the available literature that was reviewed for this research study.

Safety Audits

During the course of the study, it was recommended by the FHWA that safety-audit literature be reviewed, in addition to accident research. Roadway safety audits are widely used in Australia, New Zealand, and Great Britain. They involve a formal examination and report, by an independent and qualified examiner, on the crash potential and performance of an existing or future road project. The goal of safety audits is to identify proactively the potential safety performance through the audit process, to prevent or lessen the severity of crashes. Literature available on the topic of roadway safety audits was assembled and reviewed. The results are described in greater detail in chapter 7.

Well-Designed Before-and-After Accident Studies

While other methods focus on both problems and solutions, this method focuses on solutions. For most before-and-after accident studies, the safety problem is known ahead of time, and the objective of the study is to determine if one (or more) type of improvement is effective in reducing the frequency or severity of crashes. In general, before-and-after studies focus on a broad improvement, such as installing traffic signal control at intersections, widening the basic cross section of the roadway, installing guardrail, or implementing geometric modifications at intersections. A well-designed before-and-after accident study can provide knowledge on the expected effects resulting from the implementation of specific improvement projects on two-lane rural roads. This knowledge could then be utilized in the determination of appropriate corrective actions for specific problem areas. Although the geometric design of "treated" sites that experienced the highest "before" accident history, or experienced the greatest reduction in accidents (controlling for regression to the mean), can be identified within the sample of sites; the resulting knowledge may not define problematic situations. The feasibility of this method to yield knowledge for the knowledge base was to have been investigated as part of a separate FHWA research contract entitled, "Safety Evaluation of Intersection Design Alternatives" (Contract No. DTFH61-96-C-00055). That study is being conducted by others, and the results of that investigation were not available at the time this report was prepared.

Highway Safety Improvement Programs

Highway safety improvement programs (HSIP), which have been in place for many years, were seen as another potential source of knowledge. Project-level data could be used to define combinations of geometrics for which improvements have been implemented. Also, if available, the data could be used to determine the effect of the improvement on safety. From the perspective of this study, the source of knowledge is not just the data related to HSIP-funded projects. Non-HSIP-funded improvements, such as reconstruction projects, were found to be much more prevalent in terms of a State's overall expenditures. Such projects also include the knowledge possessed by transportation professionals, highway designers, and traffic engineers at State and local agencies that participate in the following:

- Identification of high-accident roadway sections, high-accident intersections, and other hazardous-spot locations.

- Site investigations and safety assessments performed to determine the specific accident problems and the causes or contributing factors that are related to highway design and/or traffic control.

- Project selection and planning for roadway and/or intersection improvements.

- Design of the improvement projects.

The results are described in greater detail in chapter 8.

Alternative Knowledge Source

During this research, one additional viable method for developing the knowledge base for the DRC was identified, beyond the six listed previously. While this method was not pursued or investigated in great depth, it deserves to be included in this discussion. Although this method is similar to interviews with experts, there are sufficient subtle distinctions between the two methods that it should be discussed separately.

The method relates directly to the anticipated function of the DRC: design review. If one views the DRC as an expert system that mimics the process of a senior designer reviewing a geometric design plan prepared by a junior engineer, then senior designers should apparently be considered experts. Their knowledge does not need to be based on findings of accident research studies, or on forensic investigations of specific motor vehicle crashes or high-accident sites. Up to this point in the process, it was thought that the "experts" should include the following, among others:

- Geometric designers from both the public and private sector.

- Human factors specialists who have been involved in tort liability claims and motor vehicle accident lawsuits related to highway design.

- Forensic crash investigators and expert witnesses who have been involved in determining whether the design contributed to the cause of a crash.

- Accident reconstructionists.

- Traffic engineers.

- To a limited degree, law enforcement personnel, notably those involved in traffic crash investigations.

- To a more limited degree, personnel knowledgeable in maintenance practices for two-lane rural roads.

The underlying premise has been that all these experts should be knowledgeable about highway design, especially the geometric aspects of design. The original concept was that the diagnostic approach to the Accident Analysis Module should be based on knowledge gained from crash investigations. Thus, while geometric designers are included in the list, it was thought that they would also have knowledge about highway safety.

If the position is taken that the DRC will be a design review expert system, then the experts should include senior geometric designers. Typical experts have many years of experience in designing and/or reviewing designs for the construction, reconstruction, and possibly rehabilitation of two-lane rural roads and intersections. The knowledge acquisition process would be much more analogous to the conventional expert system development, i.e., a knowledge engineer working with a series of experts to extract the rules of thumb. For example, if a selected group of senior designers was asked to review a set of design plans for a two-lane rural-road improvement/reconstruction project, then the designers may identify aspects of the geometric design to which they take exception. They may identify specific aspects that, in the interest of safety, are less than adequate. During this process, information could be solicited on the decisions and the basis for formulating those opinions. The knowledge engineer would be responsible for translating that information into logic for the expert system.

Thus, the knowledge does not necessarily have to be related to specific crashes. Based on discussions with senior State personnel, it is believed that there are many highly qualified transportation professionals with expertise in highway design who currently work in the district and residency offices of State and county highway agencies. Their collective knowledge comes from years of highly relevant experience. They have often learned from having to live with the consequences of their design decisions. For example, many can vividly describe decisions that they made during their early years that produced less that satisfactory results in terms of safety. While these individuals may never have participated in an investigation of a specific crash or an accident research study, they may have valuable knowledge about what constitutes good design and, more importantly, what constitutes bad design. Consequently, there are strong reasons to believe that a rich harvest of knowledge can be reaped from employing the formal tasking method of knowledge acquisition using these types of individuals as experts.

CRITICAL ISSUES IN THE DEVELOPMENT OF THE DRC KNOWLEDGE BASE

With respect to the development of the DRC knowledge base, several critical issues should be understood and considered. The following section presents a brief discussion of such critical issues and their implications on subsequent efforts to develop the DRC knowledge base. A distinction is made between the interactive checklist and the automated review wherever the issue relates exclusively to one or the other.

Problem Emphasis Areas and Selection Criteria

Paved, two-lane rural roads in the United States are diverse in terms of their design characteristics. They vary in terms of cross section, such as pavement width, shoulder type and width, and roadside design. They also range in terms of horizontal and vertical alignment characteristics, as well as available sight distance. The design of individual intersections, bridges, railroad grade crossings, and other features is also widely variable. Moreover, there appears to be a very wide range in the safety-deficient combinations of geometric elements and features. As a result of this research, it appears that developing an initial knowledge base that attempts to include all possible geometric problems is too ambitious. In the judgment of the research team, there is an extremely low chance for a successful outcome associated with such a robust approach. The net effect would be an ad hoc assortment of problems.

In lieu of developing a complete and comprehensive knowledge base at the start, it is proposed that the knowledge base be developed for a selected set of problem emphasis areas. It is believed that by making strategic decisions on a prioritized set of problem emphasis areas, a working prototype expert system based on a limited number of types of geometric situations can be efficiently developed and tested. This would allow highway designers working in CADD to use and beta test the prototype model. Thus, a working model could be developed and refined, based on information from users, before a full-scale comprehensive model is developed.

While problem emphasis areas are presented in chapter 9, it is proposed that the FHWA, with input from the IHSDM Technical Work Group (TWG), determine the emphasis areas for the next effort: developing a DRC prototype. It is recommended that the FHWA consider the following factors:

- The extent to which problems related to the emphasis area are commonly found throughout the United States. Unique problems or situations that occur in a limited geographic area of the country should not be selected. For example, low-water stream crossings on two-lane rural roads may be a major problem in river valleys or mountainous areas of some States, but they are virtually nonexistent in many States.

- The extent to which these problems are included in improvement projects for two-lane rural roads. For example, steep downgrades may be a problem area; however, if there are very few improvement or reconstruction projects that involve changing those grades, then the knowledge gained may have limited value.

- The magnitude and severity of crashes related to the problem emphasis area. If the problem emphasis area accounts for a negligible proportion of all crashes on two-lane rural roads, then the expenditure of funds should be redirected to some other problem area. For example, passive railroad-highway grade crossings at a skewed angle may be a problem, but the associated accident occurrence is a relatively rare event.

- The feasibility of developing design rules for analysis within a CADD-generated design plan. This point applies only to the automated review feature. Some potential emphasis areas may be difficult or impossible to program in the DRC. Before an emphasis area is selected, some thought should be given to the geometric design units of measure that describe the situation. An example would be the problem of fixed objects along the outside of horizontal curves. The plan may not contain sufficient roadside data to allow this type of problem to be flagged. If roadside data were transferable from a topographic field survey or aerial photograph, the corresponding geometric variables might include the critical curve radii, lane width, operating speeds, and offset distance to fixed objects.

Required Specificity Level

In the development of the rules of thumb that will be employed to flag a specific location, one of the major issues is, "How detailed will the description/specification in geometric terms need to be?" For example, if the problem emphasis area is "steep sideslopes," then specifications could be developed to flag the following:

- < 4:1 slopes.
- < 4:1 slopes on 2-m+ (6.6-ft+) fills.
- < 4:1 slopes on 2-m+ (6.6-ft+) fills on the outside of right horizontal curves.
- < 4:1 slopes on 2-m+ (6.6-ft+) fills on the outside of right horizontal curves with < 1-m (3.3-ft) shoulders, no guardrails, and < 7.3-m (24-ft) pavement widths.

The more detailed the specification, the more likely that the "flag" will appropriately identify a safety-deficient combination of geometrics that warrants the designer's attention. However, if the specification is too detailed, then that specific flag may never be raised, and the cost of developing the information will far exceed the value of the information. Engineering judgment needs to be exercised in this area to ensure that: (1) the conditions that truly conspire to make a particular geometric combination potentially hazardous are consistently flagged, and (2) the conditions that do not pose an unacceptable risk to the motorists are not flagged.

Although the interactive checklist feature does not require quantified threshold values, the checklist may be prompted as it identifies elements of the design. For example, the DRC could identify intersections along an alignment and prompt the user with intersection-related questions. Thus, there may be some level of specificity required to determine when checklist elements are displayed.

The Experts

As described earlier in chapter 3, certain processes lend themselves to expert systems. A design assistance tool is one such function. The DRC, however, is not based on specifications or policy, but on rules of thumb. Since there are many potential experts in this field, the resulting rules will require a consensus. Too many experts can result in disagreements that are difficult to reconcile, while too few experts may produce rules that lack the valuable input of others who are more knowledgeable. It may be the responsibility of the knowledge engineer (possibly combined with the FHWA) to combine or select the checklist items/rule specifications, based on the experts' varying responses. The first decision will be the optimal number and background of the experts. The prior selection of emphasis areas will aid in this process, because some individuals may have expertise in only certain areas (e.g., intersections, access management). During the course of this project, potential experts were defined to include the following:

- Designers with several years of experience with two-lane rural-road projects.
- Traffic engineers who conduct investigations of high-accident sites.
- Forensic crash investigators/accident reconstructionists.
- Human factors specialists who have been involved with accident investigations.

It is important to understand that these four types of individuals may possess mutually exclusive types of knowledge. Clearly, not all of them could establish detailed specifications in geometric design units of measure to define combinations of geometric design elements that should be flagged. Thus, they are not interchangeable. Frequently, one brings more relevant experience to specific types of problems than do others. For example, traffic engineers may be more adept at intersection-related problems. Human factors specialists may be more adept at vehicle-vehicle collisions and the determination of the extent to which driver error was a contributing factor or cause of individual accidents. Accident investigators may have unique abilities to render meaningful opinions about the "causal relationships between accidents and geometric design elements and features," based on extensive investigations of individual crashes. However, their knowledge may be limited solely to the individual cases in which they were involved.

Geometric designers may never have participated in a crash reconstruction or the investigation of a high-accident site, but they most certainly offer opinions as to what constitutes "good" versus "bad" design. They are also acutely aware of the issues to consider and the elements or characteristics that could be overlooked. Moreover, they may have unique experiences gained from having to hear about accidents and problems related to an intersection or section of highway for which they personally participated in the design decisionmaking or the actual design. Their knowledge could come from having made less than optimum design decisions.

Thus, the issue is which group (or groups) should be used to serve as the experts for the purpose of developing a rule of thumb to flag design elements and provide suggestions on the most appropriate corrective action.

Criteria for Problem Identification

With respect to this area, the crucial issue can be simply stated:

- What constitutes a problem? When should a combination of geometrics be included as a checklist item and/or problem to be flagged?

Other critical issues include the following:

- How can highly unique situations be avoided?

- Will the knowledge base include situations that are substandard, or will those be caught by the Policy Review Module?

- What are the criteria for including the checklist items/proposed rules for identifying a problem location?

Knowledge Acquisition From Experts

With respect to this area, key issues include the following:

- What is the proposed systematic process for interviewing experts?

- What is the most appropriate knowledge acquisition method?

- How should interviews be conducted to create:
  – Rules for identifying problems?
  – Suggestions for developing corrective actions?
  – Design checklist items?

- How many experts need to be interviewed for each problem? Are more better?

- How often should the experts be interviewed as the knowledge base is developed? Should the experts be interviewed first to identify specific problems and then later to identify corrective actions for the final list of specific problems?

- How many experts should be interviewed concurrently?

- How many interviewers should conduct interviews concurrently?

- How structured should the interviews be?

- What constitutes worthwhile knowledge?

- Can the experts develop sufficient specifications in geometric design units of measure that a knowledge representation process can convert them into something usable within the expert system?

Many of these issues are discussed in chapter 5.

Knowledge Acquisition From Site Investigations

With respect to this area, there are a host of critical issues, which include the following:

- What should the criteria be for selecting sites for subsequent forensic investigations?
- What types of sites should be visited? Where do they need to be located? Is a geographic distribution needed?
- Can a conclusion about the contributory effect at one isolated finding be transferred to a generic rule of thumb for other locations?
- With respect to accident site investigations, what about the "successes" (i.e., similar geometric situations that are not high-accident sites) that are not explicitly considered?
- With respect to forensic site investigations, is there a need to replicate at another "similar" site?

Recognizing that these investigations tend to be costly, there is a need to be judicious in selecting sites for subsequent forensic investigations . Many of these issues are addressed in chapter 6.

A Need for Pilot Knowledge Acquisition

Although this study was an investigation into potential methods for the development of a knowledge base, there is still a need to evaluate procedures and processes before launching into full-scale development of a working DRC prototype. The scope limited this research to investigating methods to develop the knowledge base for the expert system. The objective of this research was not to develop an expert system. This research has developed and/or investigated methods that are appropriate for the identification of potential problem emphasis areas. Key references on the development of expert systems clearly stress the need to employ a development team that includes a knowledge engineer, users, experts, and an advocate. Knowledge engineering capabilities did not exist in the composition of this research team. Consequently, there is still a need to pilot test the different procedures, most notably those related to interviewing experts to extract knowledge.

Earlier, in the section on problem emphasis areas, the development of a working prototype version of an expert system for a selected number of situations was proposed. It is also important to consider whether there is a need to pilot test the final interview procedures, under the direction of a knowledge engineer. This could be tried on a very small set of experts for one or more of the emphasis areas. In a similar fashion, the field investigation procedures could be employed at a few specific sites. This could provide valuable feedback before all the funds allocated for the expert interviews and forensic investigations are exhausted. The procedures could be enhanced or modified to improve the efficiency of the knowledge acquisition process. While this would be beneficial, lengthening the schedule may push the delivery of a working prototype expert system beyond the year 2000.

Policy Review Module Development Interaction

As discussed near the end of chapter 2, the DRC automated review is closely related to the Policy Review Module (PRM). The expectation is that IHSDM users will always execute the PRM before they apply the DRC. Consequently, should the developers of the DRC assume that the PRM will always "catch" substandard aspects of the geometric design alternative? If this assumption is made, then the subsequent development of the knowledge base can focus exclusively on those situations that meet minimum design standards for individual design elements, but that, when used in combination, are still problematic. However, if the opposite assumption is made, then the development of the knowledge base must consider situations with substandard geometrics.

Another aspect of this issue is related to how the PRM will be developed. At the current time, the development efforts have been devoted to using only quantified geometric design criteria in AASHTO's *A Policy on Geometric Design of Highways and Streets* that are also accessible attributes within the CADD file.[9] It is recognized that the *Green Book* also contains generalized guidelines that are not expressed in quantitative geometric terms. Most notable are the guidelines on the following:

- General controls for horizontal alignment.
- General controls for vertical alignment.
- General design controls for combinations of horizontal and vertical alignment.
- Alignment coordination in design.

Based on the current FHWA concept plan for the PRM, this initial version will not include qualitative guidelines, including the assessment of coordination between horizontal and vertical alinement. One example cited in AASHTO is the situation in which a short tangent separating two reverse horizontal curves is located on a crest.[9] The combination, which is depicted in figure 8, is deficient for two reasons. The tangent between the curves is too short, and the reverse occurs on a crest. The reason for their omission of a quantitative check is the lack of nationally accepted criteria by which each guideline is defined. Given that the PRM will not include the general design guidelines, at least initially, it may be appropriate to devise the knowledge base so that the DRC will catch these situations.

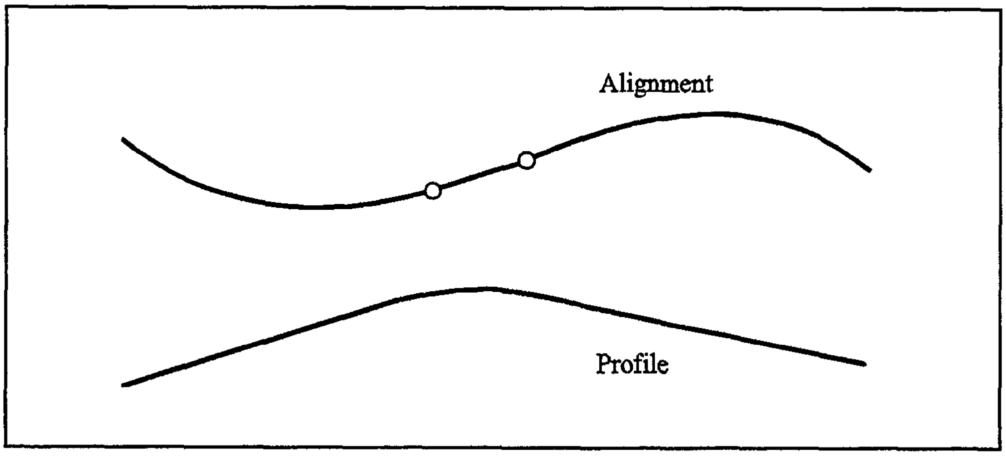


Figure 8. Illustrative general guideline for coordination of horizontal and vertical alignment.

One perspective on how this could be accomplished would be an attempt to develop the criteria that define each guideline, using an expert systems approach. It may be possible to develop specific design guidelines in geometric design units of measure to identify these situations through a knowledge engineer working with experts. For the example shown in figure 8, consider what happens if a group of geometric design experts, with the assistance of the knowledge engineer, develops explicit specifications for the following:

- The minimum length of the tangent.
- The minimum algebraic difference in approach grades.
- The minimum length of the crest vertical curve.
- The rate of vertical curvature (K).
- The minimum degree of curvature of the upstream or downstream horizontal curves.

It may then be possible to include this situation in the DRC automated review. If experts are being used to define the rules of logic to flag safety-deficient combinations of geometric elements within the CADD files, then they could also be used to establish explicit criteria that define those situations. At the very least, it may be more appropriate to integrate these qualitative design guidelines into the DRC rather than the PRM.

The DRC: de Facto Design Policy

Although the objective is not to create "new" design policies, the DRC automated review, by its very nature, will attempt to identify specific combinations of geometric elements judged to contribute to motor vehicle accidents. The implications are that these combinations should be avoided in the interest of safety. While it is not within the purview of the Safety Design Division of FHWA's Office of Safety and Traffic Operations Research and Development, nor the IHSDM Technical Work Group, nor the successful contractor to establish design policies, some may perceive the underlying logic within the DRC as a de facto set of quantified minimum design guidelines. This may pose a significant threat to wide-scale use of the DRC, because many States will not use a "black box" without formal approval of all of its component logic.

Return versus Investment

This issue is related to the value of the knowledge gained versus the cost to obtain that knowledge. As in the design process, the costs must be weighed against the advantages. The issue can be restated as, "How many problem areas and how many rules of thumb are needed to justify the cost?" Clearly, if the entire proposed plan results in the definition of rules to identify only 10 specific combinations of geometric elements, then the investment will certainly be perceived as yielding a negligible return. Perhaps just as important is the issue of quantity versus quality. Is it better to have a small set of well-supported, defensible checklists (rules), or an extensive set of unsupported, debatable checklists (rules)? The answer is likely to lie somewhere between the two extremes.

Another important consideration under this issue area is what happens if, after a forensic investigation of a specific site, the multidisciplinary team concludes that the geometrics are not at fault and that there no are problems related to the geometrics? Should this be considered a lost opportunity, or is there value in knowing that the combination of geometrics did not, at this specific location, contribute to an accident? Whether they are considered "failures" or "unsuccessful attempts," some investigations may not result in either explicit rules or checklist items. This possibility should be considered in the selection of sites.

Finally, given the risks of inconclusive investigations, there must be a limit set on how much effort should be devoted to exploratory investigations. For example, consider that there is insufficient information to adequately define the problem in geometric design units of measure, based on expert interviews. Will the knowledge void be filled by: (1) "finding" potential crash sites, and then (2) conducting forensic investigations at those sites? Although this proposed approach assumes that the design parameters can be defined in specific geometric terms, the high cost for these investigations mandates wise decisionmaking with respect to levels of investment.

Checklists: Suggested Corrective Actions

Practitioners may be concerned that the DRC does not become too prescriptive in the identification of either: (1) the problems, or ultimately, (2) the suggested corrective actions that mitigate and/or address the problem. Additionally, the checklist items must be relevant, understandable, and effective. A long or irrelevant checklist will quickly become tedious and will fail to gain the support of the user community. Highway design has never been considered something that can come out of a "cookbook." Constraints and numerous considerations, such as terrain, adjacent topography, functional classification, design speed, right-of-way issues, design volumes (both ADT and direction design-hour volumes) and the need to provide access, must be taken into account. Thus, the perception that a quick application of the DRC will create "good" design should not be promoted.

To maximize the DRC's effectiveness, feedback from potential users on the most desirable format and content of the information to be displayed is critical. This specifically relates to the checklist items and corrective actions "help" screens that would pop up after clicking on a specific flag. It is proposed that the IHSDM Technical Work Group (TWG) serve as a conduit for providing the needed inputs and reactions related to the user interface. It may also be appropriate to consider selecting a slightly larger group of beta users, who could test the prototype and provide feedback. The outside users could supplement the IHSDM TWG.

SUMMARY

This chapter expanded on the expert systems material presented in chapter 3 and introduced potential knowledge sources investigated in chapters 5 through 8. For the interactive checklist feature, the purpose of the DRC knowledge base is to determine the content of the checklists, including how and when they are initiated. For the automated review, the purpose is to determine the quantitative guidelines for flagging a location and the content of corrective actions suggested to the user. Six sources of knowledge were identified for providing data for the DRC knowledge base: (1) tort liability and court cases, (2) accident research/highway safety literature, (3) expert interviews, (4) clinical investigations by multidisciplinary teams, (5) well-designed before-and-after studies, and (6) investigations of highway safety improvement programs. Each of these sources was briefly described, to outline the associated research task. An additional knowledge source relies on the experiences and knowledge of geometric designers. Chapter 4 concludes with a synthesis of critical issues related to the development of the knowledge base. These issues include problem emphasis areas and expert selection, knowledge acquisition methods, Policy Review Module interaction, and cost/benefit constraints.

CHAPTER 5. EXPERTS INTERVIEWS RESULTS

This chapter summarizes the results of an investigation into the feasibility of interviewing experts in relevant safety and design fields, to gain insight into their knowledge of how highway design elements or features contribute to accidents. The information obtained from these experts would be incorporated into the DRC knowledge base, along with the information gathered via other methods described in the subsequent three chapters. This chapter focuses on the findings from a sample of expert interviews, and the methodology employed to evaluate the feasibility and effectiveness of this method for use in the development of the knowledge base for the DRC. Specifically, the following questions were explored:

- Will experts provide good insights as to the design elements or other features that contribute to accidents in a given situation?
- Which type of experts provide better information?
- Is phone interviewing adequate, or is a person-to-person meeting needed?
- How should the interview be structured?
- How can the information obtained from the interviews be used in the DRC?

METHODOLOGY

Six expert interviews were conducted over the telephone, with questions asked by an interviewer who referenced a preformatted questionnaire. Advance notice of the interview topic and specific questions was not provided. Two additional interviews were conducted in person at the office of each expert. One week prior to the in-person interviews, the expert was provided with the exact questions that would be asked. The subject of all interviews was two-lane rural-road intersections at or near horizontal and/or vertical curves. This single emphasis area was chosen in order to maintain a relatively focused interview. Also, it was thought that if these sample interviews were successful using this subject, the process would also work for other situations, features, and design elements of two-lane rural roads.

Interviewees

Experts in the following three fields or categories were selected:

- Highway geometric design and traffic engineering (including State or local agency personnel, design firm consultants, and expert witnesses).
- Human factors.

- Accident reconstruction/forensic investigation.

Some interviewees' knowledge came from combinations of the above areas of expertise. The persons were selected based on knowledge of their credentials, their reputation in the transportation community, and the opinions of others. Table 6 lists the experts who were interviewed, the type of interview, and their respective fields of expertise.

Table 6. Experts interviewed and their respective fields of expertise.

Expert	Field(s) of Expertise	Type of Interview	
		Telephone	In Person
Sheldon Pivnik, P.E.	Independent consultant, expert witness, former local agency affiliation.	✔	
John C. Glennon	Independent consultant, expert witness.	✔	
Timothy R. Neuman	Design engineer, consultant.	✔	
Gerson Alexander	Human factors, expert witness.	✔	
Mark A. Marek	State design engineer.	✔	
James L. Pline, P.E.	Consultant, expert witness, former State agency affiliation.	✔	
John M. Mason, P.E.	Design engineer, researcher in design and traffic operations, expert witness.		✔
Dean A. Schreiber, P.E.	State design engineer.		✔

Questionnaire and Interview

Prior to asking the pertinent questions, the interviewer provided a brief background of the project objectives and the tasks at hand. With permission, the interview was tape-recorded. This record was used to clarify and expand upon written notes taken during the interview. In this way, the interviewer could focus more attention on the substance of the discussion and devote less effort to note-taking. Recording was also used to evaluate the interview procedure and structure, in order to determine the most effective methods for facilitating a meaningful discussion to extract the desired knowledge. Following are the questions that were asked during the interview. After each question, a brief explanation of its intent and purpose is provided, along with additional procedures or prompting methods used during the interview.

Question #1: Have you ever conducted a safety assessment (i.e., an analysis of an accident, design preparation, design review, etc.) for a rural road intersection? Please explain the situation.

The purpose of this first question is to establish the potential interviewee's degree of involvement and experience related to rural road intersections and safety/design issues. The question confirms the individual's expertise level and ensures that the expert is likely to have a sound basis for expressing his or her views as to causal factors in these types of accidents. If the person did not appear to have adequate knowledge, then the interview would have been terminated. This situation did not arise during the course of the expert interviews. Following this question, it was necessary at times to explain the purpose of the interview in slightly greater detail. The expert was then able to direct his or her responses to the type of information that would be useful for the development of the DRC knowledge base.

Question #2: Given the situation of an intersection on a two-lane highway with a horizontal and/or vertical curve on the main roadway in near proximity to the intersection, in your opinion, what highway design, traffic control device, or operational features are likely to contribute to an accident?

This second question is purposely open-ended so as to provide the expert with the opportunity to communicate freely his or her opinion as to the roadway features that can contribute to accidents for this particular scenario. In some cases, suggestions or examples were necessary to initiate the thinking process, but it was believed to be more valuable to allow the expert to respond first without influence from other ideas of design elements as potential contributing factors. An initial list of features (design, traffic control, or operational) was obtained from the expert. Every effort was made by the interviewer to identify as many details as possible, by probing the expert for more information on each causal factor mentioned.

Question #3: In addition to those features mentioned above, do you feel any of the following features or conditions contribute to accident causation?

(1) Number of lanes on the main road.
(2) Number of lanes on the side road.
(3) Lack of left-turn lane on each approach.
(4) Lack of adequate intersection sight distance.
(5) Presence of driveways close to the intersection.
(6) Angle between intersecting approaches.
(7) Traffic volume.
(8) Average speed.
(9) Lane width.

This final question is simply a continuation of the second question. In this question, however, the list of potential causal features builds on each of the elements mentioned in preceding interviews. If, in question #2, the expert did not mention one of the items on the list, they were asked if they believed that a particular feature was a significant contributor to accidents. By the end of the interviews, a complete list was complied of elements that the experts deemed to be important from a safety viewpoint in the design of two-lane rural-road intersections.

After each interview, the tapes were reviewed and a transcript of relevant and useful information was produced. Also, an assessment was made as to how informative the expert was and to what degree his or her knowledge would be applicable applicable to the DRC.

SPECIFIC PROBLEM LOCATIONS

The interviews produced a variety of contributing factors related to safety problems at rural intersections at or near a horizontal/vertical curve. Each expert had his own "angle," providing opinions based on personal experiences and area(s) of expertise. For example, human factors specialists focused more on the elements related to driver perception problems, whereas expert witness interviewees relied on particular case examples for safety problem identification. For this reason, it was important to interview all types of experts, so as not to forego any important information.

Some of the information gained from these interviews is applicable exclusively to either the interactive checklist or the automated review functions. Examples of problems that could be applied only to the checklists include poor sign retroreflectivity and lack of roadside vegetation maintenance. While these are important safety issues, the DRC automated review will not be able to identify such elements. Every effort was made to direct the interview toward those topics that could be used to develop either function of the DRC.

Design features and those factors believed to contribute significantly to accidents at rural road intersections are summarized here. Some of the experts supplied quantitative explanations of the problem features, i.e., "driveways in close proximity to an intersection are a problem if located within 100 feet." The numbers varied by expert. In most cases, however, the general problem was mentioned in a more qualitative manner. These responses could be used to develop checklist items of design issues to consider. To be utilized by the automated review, these qualitative problems will need to be transformed into numerical criteria that can be compared to data from the CADD plan. Both the qualitative and quantitative problem types that were identified by the expert interviews are as follows:

- Left-turn lanes with insufficient taper and length necessary to provide adequate deceleration and storage, particularly at locations with limited sight distance approaching the turn lane. (The general consensus among the experts was that bypass lanes are a poor design choice or replacement for dealing with left turns, due to driver perceptual problems for through vehicles, and driver unfamiliarity.)

- Driveways located in close proximity to intersections, particularly higher volume driveways. Suggested minimum distances range from 30.5 mm to 91.5 m (100 ft to 300 ft).

- Severe skew angles (angle between the intersecting roadways), which cause sight-distance problems, poor path definition, and difficulties for elderly drivers. It was suggested that the intersection be relocated to provide an angle closer to 90 degrees. If this design adjustment is not possible, however, "absolute" minimums range from 60 degrees to 75 degrees.

- Absence of shoulders, which are necessary for recovery purposes, as well as for extending the sight distance for the intersection corner sight-triangle. One interviewer recommended a 2.4-m- (8-ft-) wide shoulder on both sides of all approaches for up to 305 m (1,000 ft) prior to the intersection.

- Very isolated intersections, i.e., those that are located a significant distance from a previous, upstream intersection or from a feature that requires the drivers' attention or reaction.

- Locations where one geometric feature "hides" the presence of another (the intersection), resulting in insufficient stopping sight distance and/or intersection sight distance. These geometric feature combinations that affect sight distance can vary, but include the following:

  - Sharp horizontal curve prior to an intersection.

  - Steep vertical curve prior to an intersection [if greater than 32.2-km/h (20-mi/h) difference in design speeds; flattening the curve was suggested as a safety measure].

  - Distracting feature that requires most of the drivers' attention, such as a narrow bridge or railroad crossing just prior to an intersection.

  - Cut slopes that can create corner sight-triangle limitations.

  - Any combination of the above-mentioned geometric features at or prior to the intersection.

- T-intersections with horizontal curves located on both approaches of the major road, restricting sight distance from the minor road.

- Lack of speed-reduction warning prior to an intersection, particularly in locations where the design speed is significantly lower than the operating speed. Suggestions included warning signs, rumble strips, and overhead flashers.

- Design of the side street, including too much superelevation for vehicles turning from the side street, and inadequate turning radii for large trucks.

- Presence of guardrail, signs, or other fixed objects that interfere with the intersection corner sight-triangle.

- Wye-intersections where the horizontal alignment of the major road leads to confusion as to which leg is the continuation of the main line.

Other general contributing factors were identified as relevant to accident causation at two-lane rural-road intersections, but no particular details or guidelines were attached to them. These factors included speed, volume, and channelization.

The usefulness of the information gained from the interviews varied with each expert. One type of expert did not produce better or more data than another type. Rather, the quality and applicability of the information was dependent on the individual.

ADVANTAGES, DISADVANTAGES, AND REQUIRED LEVEL OF EFFORT

Based on this sample of interviews, it was concluded that the telephone interview was a cost-effective method that could contribute to a good foundation upon which to build the knowledge base for both the interactive checklist and automated review functions. The average duration of each telephone interview was approximately 30 min per person for one specific situation of interest. It is important to recognize that additional time is required for the interviewer to prepare for and reduce the information. Additional time may also be required of the expert to prepare for the interview.

The main advantage of the in-person interviews was the level of preparation of the interviewee. By receiving the questionnaire in advance of the interview, the expert was able to prepare a well-thought-out response before the inquiry proceeded. The average duration of the in-person interviews was 45 min to 1 h per expert, per problem situation. In addition, some experts prepared case studies to explain the problem situation that they were describing.

There are, however, some disadvantages to both types of interviews. One particular characteristic of the experts that were interviewed is that many of them work in the private sector and their time is quite valuable. Therefore, the cost to the expert is high, and the time they are willing to spend on the interview is limited. Also, prior to the telephone interviews, the experts were not notified as to the objectives and the type of information that would be discussed. Advanced notice of the topics and perhaps even a direct copy of the questionnaire would have encouraged a more well-thought-out interview.

The primary disadvantage of the in-person interviews is the cost and travel time of the interviewer. Lastly, these interviews were strictly one-on-one, as opposed to bringing together groups of experts to interview together. This type of atmosphere allows for no interaction or collaboration among experts. This may be an advantage to some extent; however, arriving at a consensus on a particular design element or checklist item may be difficult with several experts in one room. Collaboration may be more useful as a second-phase effort, with different parties involved, after an initial list of checklist items and/or quantitative rules are identified through individual interviews. These issues are discussed further and taken into account in the recommended experimental plan (see appendix A).

DRC KNOWLEDGE BASE DEVELOPMENT IMPLICATIONS

Through interviews with a sample of experts, a better understanding was achieved as to the type of information that can be extracted for use in the DRC knowledge base, as well as the methods that are best for extracting this information. One problem encountered during the course of many of the interviews was that it seemed that more-detailed and fruitful discussions could have evolved given more time. (One interview was conducted while the expert was en route to another meeting, under time-restrictive conditions.) Perhaps monetary compensation for the experts' time is needed to allow for a more lengthy and thorough interview. Also, the telephone may have restricted the delivery and understanding of some information. If the interviews were conducted at the office of the expert, files and specific safety-problem location data could be retrieved. Given more time and more direct interaction, additional knowledge could be extracted from these experts.

Also, a point of diminishing returns is evident. After the third or fourth interview, very little additional knowledge was obtained. Thus, for a given problem situation, a maximum of four to five persons should be able to provide the information sought for the knowledge base.

It is recommended that each expert be contacted prior to the interview with a list of problem emphasis areas that are to be investigated. In so doing, the interviewer may be able to inquire as to each expert's degree of knowledge in these areas. The research team will be able to control the overall interview process with a better understanding of the feasibility of extracting the necessary knowledge for a given scenario. If chosen, the expert should be given ample time (1 week minimum, 2 weeks preferable) and information to allow thorough preparation prior to the interview. The information provided to the expert will depend on whether the interview objective is to develop the knowledge base for the interactive checklist or for the automated review.

Most of the safety problems that were identified through this process were qualitative in nature. The experts did not directly identify a numerical guideline from which the automated review could base its logic. Therefore, the results of this initial sample of interviews can be used to develop a list of problem location types or geometric features for which checklist items and/or numerical rules could be generated. In other words, these interviews did not create an end product themselves; rather, they identified a list of areas that need further refinement and specification before they are entered into the knowledge base. A second set of interviews with experts could be conducted, with the objective of either: (1) developing questions for the interactive checklist to address the emphasis areas, or (2) attempting to specify numeric criteria for the automated review.

Further interviews to develop the interactive checklist would consist of brainstorming sessions in which the experts are asked to generate a set of questions that should be asked for each scenario. It may be appropriate in this case to employ group interviews or focus groups, since the ideas of one expert may spur discussion and criticism from other experts. The result is a synergistic process in which the expertise of each member is reflected in the checklist items and wording.

By probing the experts for specifics for each element, the research team could obtain numerical guidelines for the automated review. For example, given the problem situation "inadequate left-turn lane taper and bay length," the interviewer would inquire, "At what length does this become a problem?" If this question results in an answer that generates investigation into more geometric elements (i.e., "the length required for storage and deceleration depends on the sight distance upon approach to the turn lane"), then these elements will also be investigated to develop quantitative guidelines. It was concluded that for these purposes, a one-on-one interview is most appropriate. Collaboration among experts is not required here; in fact, it might hinder individual thought.

If some experts were compensated for their time, greater thought and attention to detail could be achieved. The structure of the interview should attempt to maintain a consistent format, with the realization that different types of experts will result in differing opinions on the specification of problems.

The interviewer must direct the discussion and leading questions to the individual's area of knowledge. In this way, the most valuable information will be gained from each expert, resulting in a comprehensive knowledge base. The proposed systematic process for conducting these interviews, based on the lessons learned through the sample of expert interviews, is documented in detail in the experimental plan (see appendix A).

SUMMARY

This chapter presented the findings from interviews conducted with experts in geometric design, traffic engineering, human factors, and accident reconstruction/forensic investigation. The interviews focused on a single problem area—an intersection of two-lane rural roads at or near horizontal or vertical curvature.

A total of three questions were posed to each interviewee. The first was asked in order to gauge the respondent's experience in the subject area. The second question was open-ended, allowing the expert to specify the design or operational features that could contribute to accidents. The third question reviewed a number of potential answers, and the expert was asked to analyze the importance of each as a contributing factor to an accident occurrence at this hypothetical situation. A number of problematic features were identified by the experts, including poorly designed left-turn lanes, driveways in close proximity, skewed intersection angles, absence of shoulders, and hidden intersections.

The telephone interviews yielded cost-effective results for developing a set of emphasis areas for the DRC knowledge base. The in-person interviews included advance notice of the questions that would be asked, and this proved effective. The disadvantages of telephone interviews could be overcome by providing the questionnaire in advance of the interview, compensating the respondents, and conducting some interviews in person.

For both the interactive checklist and automated review features, the knowledge extracted in this study needs further refinement. Focus groups may be the most appropriate format for developing the interactive checklist, while a maximum of five individual interviews are preferred for the automated review.

CHAPTER 6. FIELD INVESTIGATION RESULTS

This chapter presents results from a limited number of site investigations conducted at intersections of two-lane rural roads in Minnesota. The investigations were performed by a three-person team that consisted of a local traffic engineer with experience in highway design and accident reconstructions, a human factors specialist with extensive experience as an expert witness in accident cases, and a traffic engineer/highway safety researcher with experience in site-specific safety assessments. It is important to note that the purpose of these investigations was to assess the feasibility of this approach as a viable and cost-effective means of extracting knowledge for the DRC knowledge base.

To provide a more manageable focus for this feasibility study, the decision was made to limit the investigation to two-lane rural-road intersections at or near horizontal and/or vertical curves. The rationale for this decision included the following: First, it was thought that there would be an adequate sample of candidate sites. Second, it was felt that the requirement of horizontal/vertical alignment would result in a greater diversity in the geometric configurations of intersection sites. Third, the crash problems at these types of intersections were more likely to be related to highway geometric features, rather than entering volumes and traffic control.

METHODOLOGY

For this feasibility investigation, the decision was made to utilize the FHWA's Highway Safety Information System (HSIS). The HSIS is a roadway-based system that provides quality data on numerous crash, traffic, roadway, and other variables. The HSIS uses data that are annually provided by selected States, processed into a computer format, documented, and prepared for analysis. Currently, data are maintained for the following eight States: California, Illinois, Maine, Michigan, Minnesota, North Carolina, Utah, and Washington.

Only sites from Minnesota were used in this investigation. At the time this analysis was completed, Minnesota was the only HSIS State that had both an intersection file and a photolog system that allowed the user to view a series of images on the major approaches to the candidate intersection sites. Moreover, as part of an earlier research effort conducted by Bared, "as-built" geometric design plans had been collected for a selected number of two-lane rural-road sections in Minnesota.[26] For each intersection record, Bared added data variables related to grade, expressed as a percent, and horizontal degree of curvature, expressed in degrees.

The process consisted of the following steps. First, all candidate intersection sites from the two-lane rural-road sections studied by Bared were identified and extracted into an intersection-based file. This consisted of approximately 500 potential intersection records. Accidents reported during 1993 and 1994, which were the latest years available at the time this analysis was conducted, were then matched to this intersection extract file. In an attempt to identify intersection sites that had horizontal and/or vertical curves in close proximity, two accident counter variables were created and appended to the intersection records. The first tallied the total number of crashes reported to occur within 152 m (500 ft) of the intersection during that 2-year period. The second counted the number of crashes for which the roadway character cited by the investigating officer involved a horizontal curve, a grade, or a vertical curve. It was presumed that a curve would be in close proximity to the intersection if the road character for a large proportion of the reported intersection crashes was not simply "straight and level." This process yielded a total of 28 candidate four-legged intersections and 47 candidate three-legged intersections that had three or more reported accidents during the 2-year period. Of these, a total of 19 intersections was identified because they had either: (1) high values for the grade and/or horizontal curvature variables, or (2) two or more reported crashes in which the road character was not "straight and level." Each of these 19 intersections was then reviewed on the videodisc photologs. After review, the decision was made that the potential list of candidate intersection sites was inadequate in terms of sample size.

The next step in the process was to enlarge the sample by including all two-lane rural-road intersections in the Minnesota intersection file, not just the intersections for which as-built plans were available from the Bared study.[26] Thus, the potential population was expanded to 1,438 three-legged intersections (e.g., T-intersections and Wye-intersections) in which the side road was stop-controlled, and 1,733 four-legged intersections with a stop control on the side-road approaches. Additional screening to ensure that all approaches were two-lane rural roads reduced the total sample to approximately 3,000 intersections. Accidents reported during 1993 and 1994 were then matched to the rural-road intersections. Again, the two accident-based counter variables were appended. Counting only those accidents in which the road character involved a horizontal and/or vertical curve or grade, with road character other than "straight and level," the mean 3-year accident frequency was 0.24 crashes per year, with a standard deviation of 0.898. In fact, only 66 intersections (1.1 percent) had three or more crashes in which the road character was cited to involve a horizontal curve and/or vertical curve or grade. This resulted in the identification of an additional 22 candidate intersections, although neither as-built plans nor grade or horizontal curvature information was available for these additional intersections. Photologs for the additional intersections were then reviewed with the FHWA Contracting Officer's Technical Representative (COTR). The decision was made to exclude several candidate intersections because they appeared to have left-turn lanes, three-lane sections, or overhead intersection flashing beacons, or were more suburban in nature with higher volumes.

From the combined list of 41 intersections, 17 sites were selected for further investigation. The mean 2-year accident frequency of those 17 sites was 14.1 crashes per intersection. By comparison, the mean 2-year accident frequency for the 3,000 possible intersection sites was 1.17 crashes per intersection, with a standard deviation of 2.27.

Accident rates for these 17 intersections were calculated, although daily entering volumes for some legs of selected intersections were missing from the data set and therefore could not be used in the calculation of the rate. It was determined that a majority of these intersections had rates well above 1.0 crashes per million entering vehicles (MEV). The rates ranged from 0.65 to 8.87 crashes per MEV. Based on the intersection sample size, the accident rates, and a photologs review, it was concluded that these sites were suitable for field investigation.

Individual hard copies for all crashes reported at these intersections were requested, obtained, and reviewed. Photographs, statistical summaries of selected crash characteristics, and the hard copies of the reports were then distributed to the multidisciplinary team prior to departure for Minnesota.

One member of the team was assigned the responsibility of preparing collision diagrams for the 17 intersection sites, using the hard copies of the individual records. Copies of these collision diagrams were provided prior to visiting the sites. It was determined that collision diagrams for intersections are highly useful, and they facilitate the determination of cause and effect. They can effectively show accident patterns, which can then lead the team toward the identification of appropriate contributing factors related to highway design. It is highly recommended that collision diagrams be prepared for all sites that will be investigated as part of the effort to develop the knowledge base for the DRC.

The multidisciplinary team, with the FHWA COTR, traveled to Minnesota and conducted investigations of each site. The site investigations were completed and conclusions were discussed among the investigation team.

SPECIFIC PROBLEM LOCATIONS

A variety of problem locations was investigated. A summary of the types of intersection-related design problems is presented in succeeding paragraphs. More-detailed discussions of the site investigations can be found in appendixes B and C of this report. Appendix B was prepared by the human factors specialist. Appendix C was prepared by a traffic engineer with experience in geometric design and accident investigation.

T-Intersections With Bypass Lanes

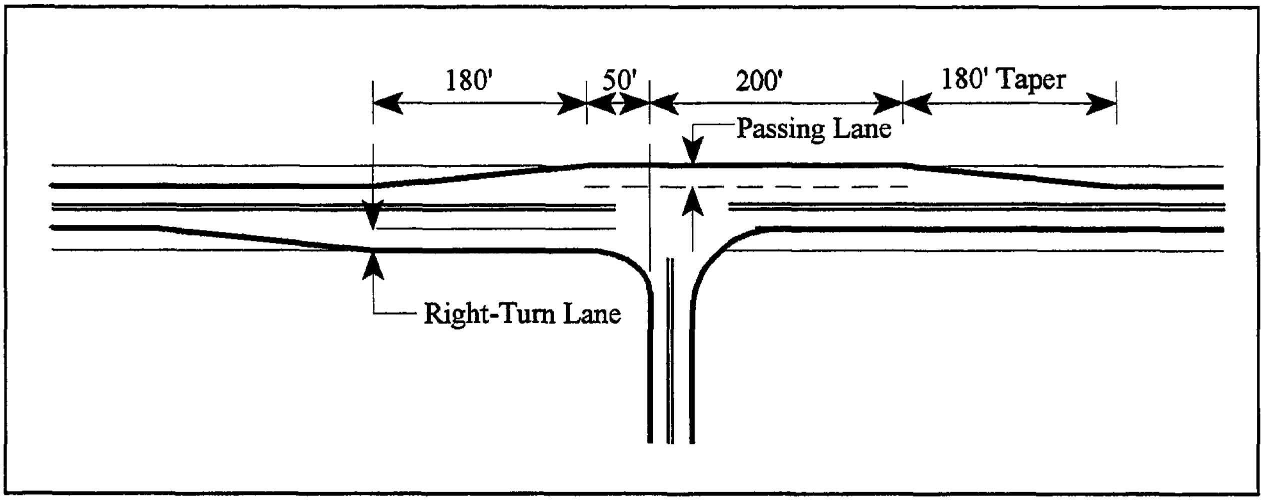
During the field investigations, it was discovered that Minnesota makes extensive use of shoulder bypass lanes at both three-legged, T-type, and four-legged intersections. Shoulder bypass lanes are often used as a low-cost alternative to providing full-width left-turn lanes at intersection approaches. Drivers proceeding through an intersection with a shoulder bypass lane can use this lane if they encounter a vehicle turning left ahead of them. In the absence of a left-turning vehicle, drivers of through vehicles do not need to use this shoulder bypass lane.

According to a 1987 FHWA informational guide on low-cost methods for improving traffic operations on two-lane roads, where an adequate paved shoulder is already available, the installation of a bypass lane may be as simple as remarking the highway edgeline.(27) Provision of a bypass lane is often much less expensive than the construction of a full-width left-turn lane. At some locations, construction of a paved shoulder for use as a bypass lane may be justified either to improve traffic operations or reduce accident experience.

While the *AASHTO Green Book* presents guidelines for establishing the need for full-width left-turn lanes on two-lane highways, no application guidelines determine when shoulder bypass lanes should be installed at intersections. Explicit application guidelines are also not found in a 1987 FHWA information report.[27]

Some States have adopted design criteria for shoulder bypass lanes. Figure 9 presents Minnesota's design guidelines for bypass lanes at intersections. As shown, the design guidelines call for a minimum taper length of 54.9 m (180 ft) for both the approach and the approximately 76.2-m- (250-ft-) long passing lane. Additional guidelines for the design of shoulder bypass lanes can be found in the 1987 FHWA information guide:

> "Shoulder bypass lanes should be not be too long because drivers may mistake it for a passing lane or feel that they are required to use the bypass lane even when no turning vehicle is present. The total length of a shoulder bypass lane should typically be 76 to 153 m (250 to 500 ft) depending on traffic volumes and site conditions. . .
>
> "The approach and departure tapers should be relatively short because most vehicles use shoulder bypass lanes at reduced speeds. Typical taper lengths for shoulder bypass lanes are 15 to 31 m (50 to 100 ft). Where a shoulder bypass lane is used, it should be designed to encourage drivers to slow down before entering the bypass lane. . .
>
> "The length of the approach lane should be...long enough to accommodate the maximum number of left-turning vehicles expected to be stopped at any one time. At the flow rates found on most two-lane highways, an approach lane length of 31 to 61 m (100 to 200 ft) can be used. The departure lane is typically 15 to 31 m (50 to 100 ft)."



1 ft = 0.305 m

Figure 9. Minnesota's design criteria for a bypass lane at a T-intersection.

Figure 10 illustrates one intersection site with a shoulder bypass lane. Four of the eleven reported crashes reported at this site over a 2-year period were rear-end collisions involving a vehicle turning left from the northbound approach. The posted speed limit on the major approach was 80 km/h (50 mi/h). The average daily traffic (ADT) volumes on the major and minor roads were 9,850 vehicles/day and 6,050 vehicles/day, respectively. However, neither directional-approach hourly volumes nor turn-movement count data were available for this intersection.

The length of the approach taper is about 49 m (160 ft). The length of the full-width shoulder bypass lane is approximately 116 m (380 ft), which consists of 46 m (150 ft) before the centerline of the intersection and 70 m (230 ft) after the centerline of the intersection. The northbound approach is at the end of a -3.5-percent downgrade. About 122 m (400 ft) upstream of the intersection on the northbound approach is a left horizontal curve.

Each of the three investigators thought that it was difficult to perceive the side road on the northbound approach. The side-road approach is on a slight upgrade. Trees and the topography along the west side of the highway restrict sight distance to some degree. It was hypothesized that the combination of limited sight distance to the intersection and the downgrade may have contributed to the rear-end crashes in that northbound drivers may not have been able to react safely to a vehicle turning left.

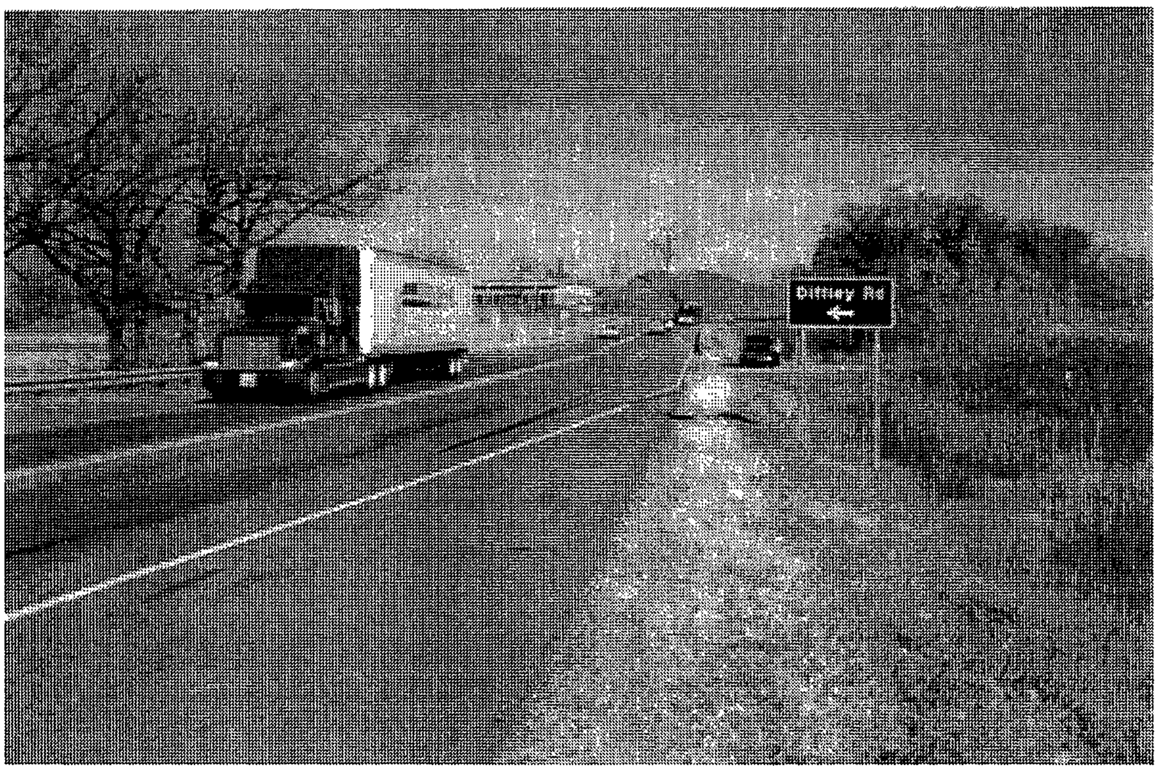


Figure 10. Photograph of a T-intersection site with a short bypass lane.

Figure 11 depicts another T-intersection with a bypass lane that was investigated as part of this effort. Of the 15 crashes reported at this intersection site over the 2-year period, 10 involved a vehicle turning left from the northbound approach, which has a posted speed limit of 88 km/h (55 mi/h). The ADT on the major road was 23,850. The side road had an ADT of 2,550. Turn-movement count data, which were obtained from the Minnesota DOT, revealed that the a.m. and p.m. peak-hour left-turn volumes were 84 veh/h and 44 veh/h, respectively. Expressed as a percentage, approximately 6 percent of the peak-hour northbound approach volumes turned left. Moreover, it appeared that the major road had high truck traffic. A 15-minute count taken during the lunchtime hour by one of the investigators revealed that 17 percent of the traffic on the major road was large trucks.

Compounding the problem was a large billboard sign on the right. It was hypothesized that this sign attracted drivers' attention, at least momentarily, which could account for some rear-end crashes. The guardrail on the right, which ran the length of the bypass lane and was approximately 0.61 m (2 ft) from the edge of the travel way, restricted the effective width of the recovery area adjacent to the bypass lane, and may pose a secondary crash hazard.

It was concluded that the combination of high speeds, high traffic volumes on the major road, a noticeable percentage of heavy trucks, and a potentially distracting billboard sign may have contributed to the rear-end crash problem.

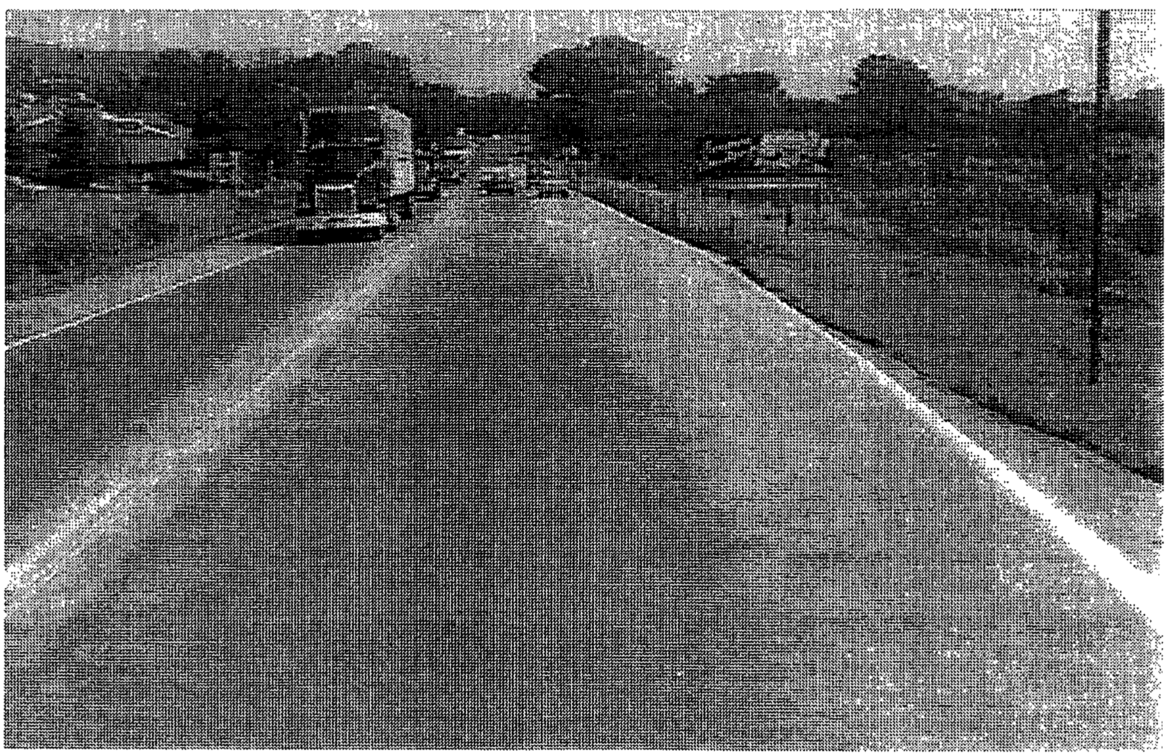


Figure 11. Photograph of a second T-intersection site with a bypass lane.

Isolated, Very Sharp Curve at a Wye-Intersection

One intersection experienced a very high incidence of single-vehicle, run-off-road crashes in which the vehicles ran off to the right. The intersection is shown in figure 12. Compared with other sites visited, this was a relatively low-volume intersection. The ADT on the major road was 1,350 and the ADT on the side road was 350. A review of individual police accident reports revealed that the accident problem was more related to the alignment than to the presence of the intersection. All 10 reported accidents were single-vehicle, run-off-road accidents. A majority of the crashes occurred during the summer. Speed was a contributing factor in seven of the crashes. Two drivers were also cited for driving under the influence. The review of the accident reports also revealed that 8 of the 10 drivers were less than 24 years old.

The posted speed limit on the major road is 88 km/h (55 mi/h), although there is a left-turn warning sign with a 40-km/h (25-mi/h) speed advisory supplemental plaque placed 107 m (350 ft) upstream of the point of curvature for the horizontal curve. This approach has a slight downgrade. The "open" area in and beyond the curve is void of vegetation, trees, or other foliage that would provide additional information about the alignment to the driver. The intersection is formed by a side road on the right. It was determined that this is a very sharp curve, much sharper than any of the slight curves encountered in the 16 km (10 mi) of primarily tangent upstream roadway.

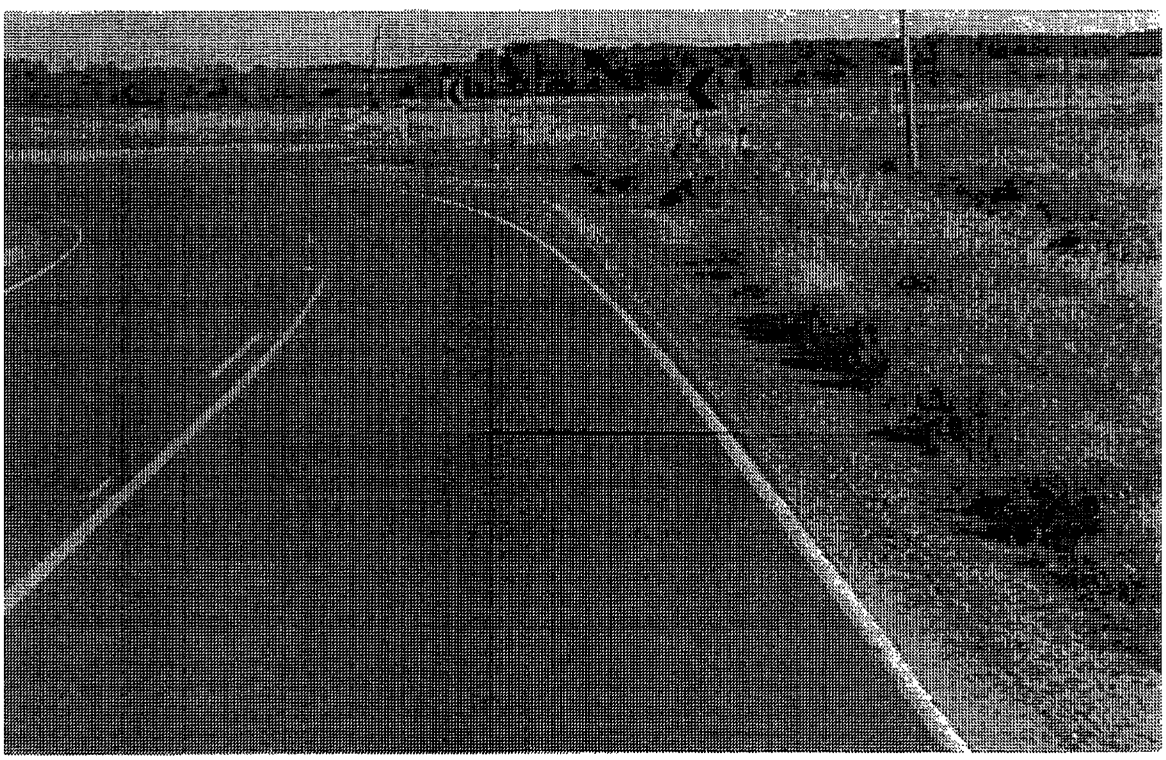


Figure 12. Intersection site on a very sharp horizontal curve.

Sharp Reverse Curve on a Downgrade Just Off an Interchange Ramp

At another site, five of the nine reported accidents were run-off-road crashes. Only two accidents were deemed to be intersection-related. Most were curve-related. The field investigation revealed a sharp reverse curve, which can be seen in figure 13, on one approach. It was discovered that traffic may be traveling southbound on this State route after exiting a freeway, which is located just to the north of this intersection. It was conjectured that the expectations of drivers may be violated when they encounter this sharp reverse curve after traveling on a 105-km/h (65-mi/h) freeway.

A review of hard copies of the police accident reports revealed a series of extenuating circumstances. For two different crashes, the drivers who ran off the road were driving stolen vehicles and attempting to elude police. Speed was a contributing factor for both crashes on the southbound approach. Two of the remaining crashes involved vehicles hitting deer. Speed was also a contributing factor in four other crashes, one of which involved a vehicle turning left onto the side road and another in which the driver was cited for driving under the influence.

At the time of the field investigation, it was noted that there was a reverse-curve warning sign with a 56-km/h (35-mi/h) speed limit on the northbound approach. There were no upstream curve warning signs for the southbound approach, although an intersection warning sign was present.

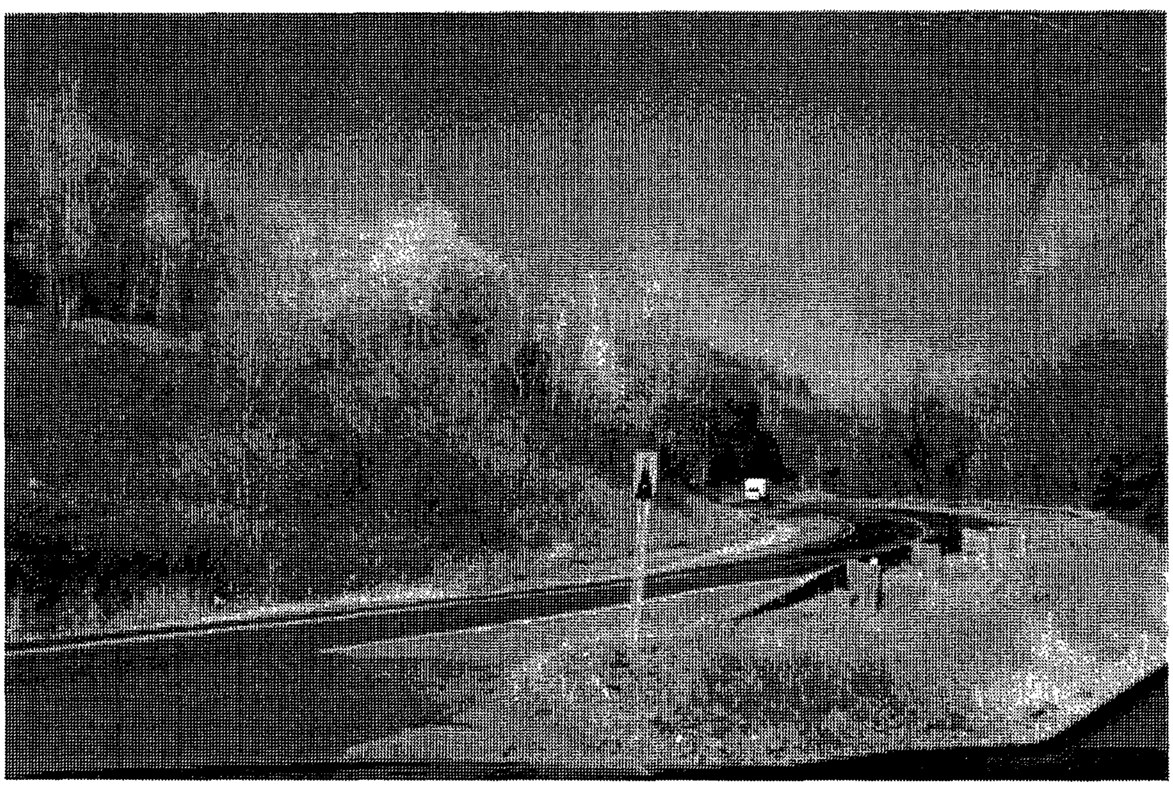


Figure 13. Intersection site with a sharp reverse curve on one approach.

Four-Legged Offset Intersection With a Skewed Approach

Figure 14 is a photograph of one intersection that appeared to experience a range of crash types. There was a total of 11 crashes reported over 2 years. Of these, four were rear-end collisions on the major road, two were angle collisions involving vehicles from the side-road approach, and one was determined to be related to the curve. The ADT on the major road was 8,400. The ADTs on the minor roads were both less than 1000. The posted speed limit on the major road was 88 km/h (55 mi/h).

The intersection is located on a horizontal curve with bypass lanes in both directions. There is a 27-m (90-ft) offset between the eastern side-road leg, which intersects at a 90-degree angle, and the western leg, which intersects at approximately 45 degrees. Field observations revealed that many drivers attempt to turn left from the major road at a high rate of speed. There is little margin for safety as drivers attempt to use small gaps in opposing traffic.

A check of the intersection sight distances revealed that from the skewed side-road approach, there are more than 244 m (800 ft) of sight distance to both major approaches. From the perpendicular road approach, there are 244 m (800 ft) of sight distance to the right, but only 183 m (600 ft) of sight distance to the left. Due to roadside vegetation and the curve, a driver on this approach must move into the bypass lane on the major road to see traffic approaching from the left.

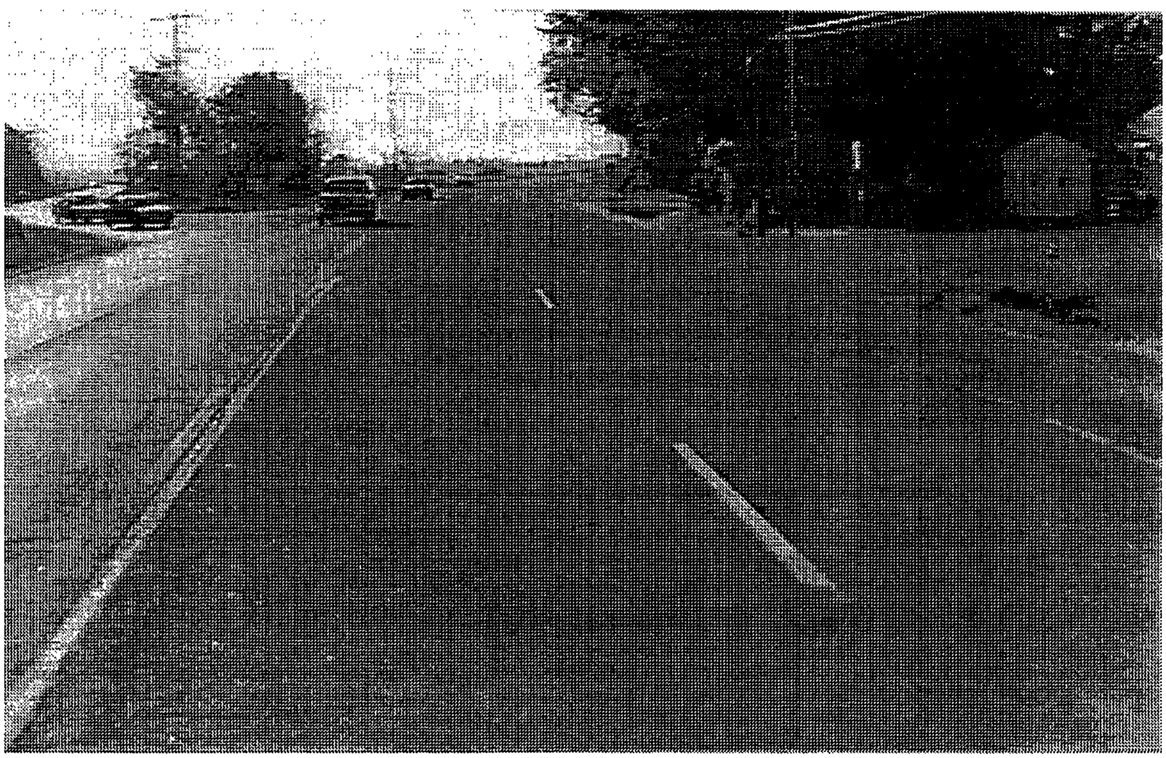


Figure 14. Four-legged intersection site with an offset, skewed leg.

Three-Legged Intersection on a Horizontal Curve With a Bypass Lane

Figure 15 shows the eastbound approach to a tangential intersection. The major road, which curves to the right, has an ADT of 12,100 prior to the intersection and 8,500 beyond the intersection. The posted speed limit on the major road is 80 km/h (50 mi/h). The minor road, which has an ADT of 3,700 and runs in an east-west direction, provides access to a residential area and can be used as an alternate route to a major north-south highway in the region. There is a slight offset between the centerline on the major road and the centerline on the side road. Sight distance from the side-road approach to the left was measured to be more than 244 m (800 ft), but the alignment makes it difficult for drivers on the side-road approach to look back to the east, due to the skew. The eastbound alignment on the major road consists of a 5-degree, 152-m- (500-ft-) long horizontal curve, which is clearly visible in the photograph, and a -2.5-percent downgrade.

A review of the reported crashes revealed that 9 of the 11 reported accidents were rear-end collisions involving vehicles on the side-road approach. The pattern was remarkably similar. The narratives indicated that the driver of the first vehicle started and then stopped. The driver of the second vehicle then rear-ended the first vehicle. Although it could not be confirmed from the available data, drivers proceeding straight from the side road may stop suddenly if they encounter an opposing left-turning vehicle from the major road. To confirm this hypothesis, additional field data would need to be collected.

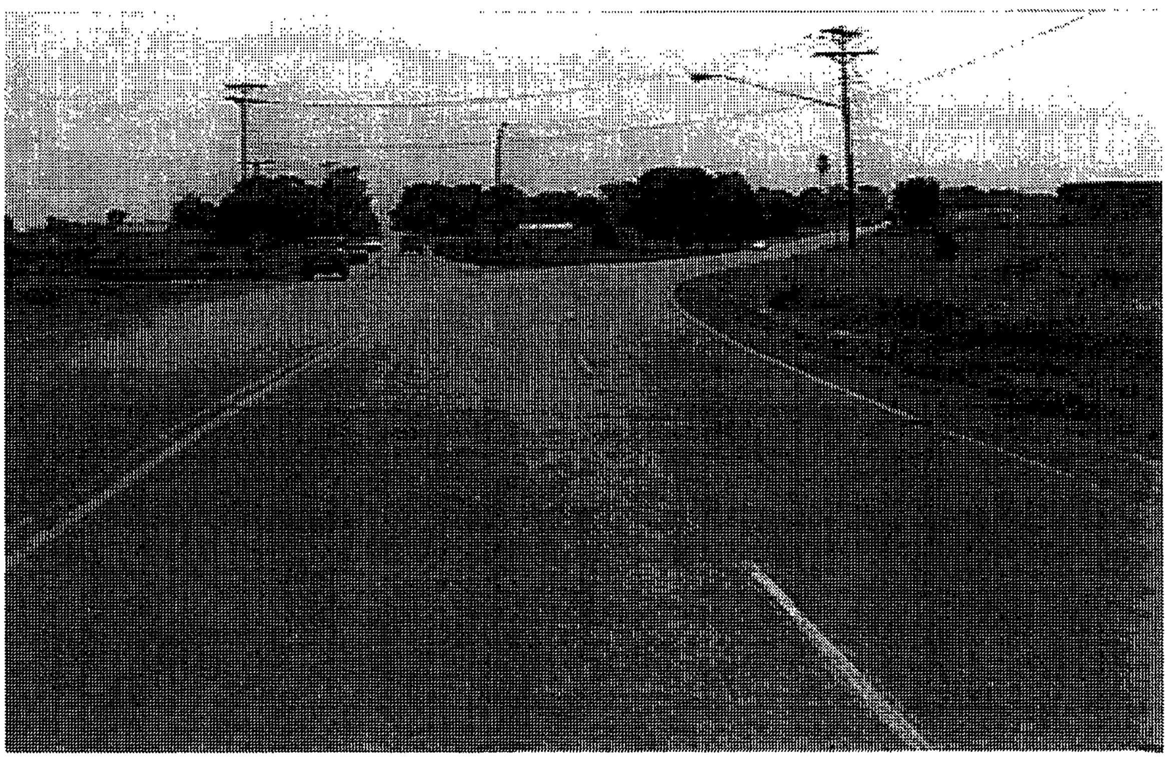


Figure 15. High-accident intersection on a horizontal curve.

Locations Where Changes Had Been Implemented

Of the 17 intersection sites, changes had been or were being implemented at seven sites. It was somewhat reassuring to know that others had also recognized these intersections as problem locations and had implemented physical geometric and traffic changes to improve those situations. The types of "before" geometric conditions and the type of improvement implemented are summarized in table 7.

Table 7. Locations where changes had been implemented.

Intersection Description	Crash Patterns	Improvement Implemented
Four-legged intersection with bypass/right-turn lanes, curved approach on major road. On one of the side-road approaches, a RR at-grade crossing, and the RR runs parallel to the main road.	High incidence of multi-vehicle, right-angle crashes.	Multi-phase traffic signal control implemented and full-length left-turn lanes striped on major approaches.
Y-intersection on upgrade. Crest curve on major road just beyond intersection severely limits intersection sight distance.	High incidence of multi-vehicle rear-end collisions.	Intersection and side road relocated to form a 90-degree T-intersection with long left-turn lane and two-lane side-road approach.
Skewed intersection located beyond a sight-restrictive crest curve on a moderate left horizontal curve.	Mostly right-angle and rear-end crashes involving younger drivers. (A high school is located just off one of the side-road legs.)	Overhead flashing beacons and all-way stop control implemented.
Four-legged intersection with bypass lanes and overhead flashing beacons, located at top of sight-limiting crest curve.	High incidence of multi-vehicle right-angle crashes.	Major road widened to provide full-length left- and right-turn lanes, crest curve reduced, multi-phase traffic signal control implemented.
Four-legged intersection with short bypass lanes and sight-restricting crest curve.	High incidence of rear-end and right-angle crashes.	All approaches widened, full-length left-turn lanes added, traffic signal control installed.
T-intersection, reverse on side-road approach, high-speed, high-volume major road. Slight downgrade on side road.	After rejecting deer crashes, no apparent crash problem related to geometrics.	Auxiliary lane being added in westbound direction, possibly as a capacity improvement for a downstream intersection.
Four-legged intersection on a slight downgrade.	Mostly multi-vehicle crashes (rear end, right angle, left turn).	Traffic signal control installed.

Based on these investigations, some illustrative geometric guidelines were developed by one of the investigators. These are summarized as follows:

- For intersections in areas of hill and curve combinations, the minimum intersection sight distance should be 259 m (850 ft).
- Full-length left-turn lanes with adequate tapers should be provided when mainline traffic volumes exceed such values as those shown in figure 16.
- Skewed approaches to the mainline at intersections should be avoided.
- Offset intersections should be avoided.
- Entrances or driveways in bypass right-turn lanes or within 152 m (500 ft) of an intersection on the through highway should be avoided.
- The use of bypass lanes at four-legged intersections should be limited to intersections with low-volume side roads. Other alternatives should be considered when the side-road average daily traffic volumes exceed 1,000 vehicles per day.

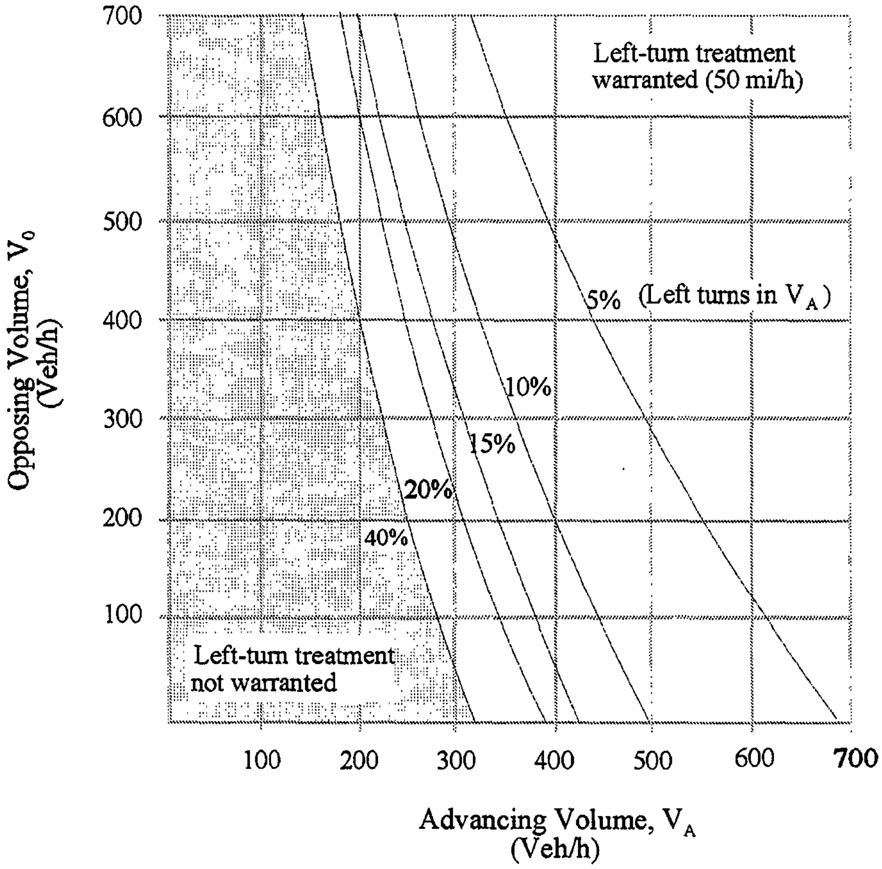


Figure 16. Minnesota's criteria for establishing the need for full-length left-turn lanes.

ADVANTAGES, DISADVANTAGES, AND REQUIRED LEVEL OF EFFORT

The relative advantages of multidisciplinary forensic investigations of high-accident sites as a means for developing the knowledge base for the DRC include the following:

- Detailed geometric specifications could be developed to describe the site. As opposed to interviewing experts or reviewing the literature, each site can be quantified in geometric design units of measure. Available intersection sight distance and other sight-distance measurements, expressed in either time or distance, can be made in the field. Much of the geometric information can be extracted from as-built plans, if available. Taper and storage lengths for auxiliary lanes, bypass lanes, and turn lanes, if present, can be measured. It is recognized that superelevation cannot be directly measured, but a trained eye could make a judgment on the order of magnitude of the superelevation or the superelevation run-off. If necessary, photogrammetry techniques or a field survey could also be used to derive more accurate estimates of degree of curvature, central angle, length of tangent approaches, and other discernible elements of an alignment. Thus, detailed geometric specifications can be obtained.

- Application of the same procedures by the same team of experts would yield uniformity and consistency across findings.

- Conclusions drawn by a multidisciplinary team are based on actual field investigations, supported by personal opinion, engineering judgment, or hypothetical cases. In addition, the conclusions involve the synergistic efforts of a group, rather than the opinion of a single expert analyzing the problem in isolation from other experts.

- The approach attempts to generalize knowledge and/or geometric specifications from actual high-accident locations, to prevent or mitigate the impact of similar designs elsewhere. Thus, there is an effort to "learn from our mistakes" by translating rules into the knowledge base and disseminating the results to other designers through the IHSDM.

The relative disadvantages of this approach are as follows:

- This approach is intended to generate design guidelines in geometric design units of measure; therefore, this method is not required to develop the interactive checklist function of the DRC.

- This approach focuses solely on "problem locations" and does not attempt to consider similar situations, with highly similar geometric design characteristics, that are not high-accident locations. For example, if one fails to consider the "successes," as recommended in FHWA's *Accident Research Manual* and as advocated by a large component of the highway safety research community, then erroneous conclusions about the contributory effects of geometrics could be drawn.[28] For example, 1 intersection site out of 1,000 similar sites with nearly identical geometrics may be judged to be potentially problematic. Basing rules of logic on this one case, in essence, disregards the fact there were 999 sites with similar geometrics that did not result in crash problems.

- Differentiating potential confounding influences may not be possible. For example, the geometric design may be adequate for a low-volume intersection, but it could become hazardous as volume or speed or percent of trucks increases. For this illustrative example, the confounding influences could be volume, speed, or vehicle mix.

- The findings are based on a sample size of one site only. This issue is somewhat related to the first bulleted item. How much credence will designers place in a specific problem if it is based on the investigation of only one isolated site?

- This method is costly. As discussed under the level of effort, the cost to conduct these investigations is likely to be very high.

- For some site investigations, extracting knowledge for the DRC knowledge base may not be possible. This could be because the true causal factors of the crashes are not related to the roadway/intersection design.

- By visiting only "current" high-accident locations, the knowledge of previous problems studied and treated and the types of treatments implemented are neglected.

In terms of the level of effort required for this method, it is relatively high to very high. Due to the need to use personnel with sufficient experience and expertise in site investigations, the labor costs for a three-person team for the site investigations alone are high, especially compared to phone interviews. In addition, lacking a set of accurate as-built plans, an extensive amount of time may be required to collect field data. Moreover, the costs related to the manipulation of the data sets and the identification of preliminary candidate sites can also be very high. Again, the data collection and specification of design features can be applied only to the automated review function. Multidisciplinary investigations may not be necessary to develop the interactive checklist feature, since it does not rely upon numerical criteria.

DRC KNOWLEDGE BASE DEVELOPMENT IMPLICATIONS

This section presents a discussion of the significant lessons learned from the feasibility investigation and their implications on development of the DRC knowledge base. The discussion includes topics related to the methodology used to identify the candidate sites, procedures employed in the field, and the method for translating conclusions drawn from the investigations into the knowledge base.

Identification of Candidate Sites

Accident frequency alone cannot be used to identify high-accident intersections. Accident research has confirmed that total entering volume has a significant effect on the expected number of crashes at an intersection. Consequently, accident rate or some combination of accident rate and average annual accident frequency should be used.

When high-accident intersections are being identified, the accident data should be screened to exclude certain types of accidents. One example is vehicle-deer crashes. During the field investigations, it was recommended that deer crashes not be included in either high-accident location identifications or forensic investigations. The argument was that deer crashes are somewhat random events and are not related to geometric conditions. In the assessment of cause and effect, design-related features generally do not cause deer crashes. It is recognized that sight-distance improvement, increased clear zone, and other measures may allow more drivers time to react to a deer in the road; however, this does not mean that sites with wide clear zones and good sight distance will have far fewer deer crashes than two-lane rural roads with restrictive sight distance and a limited clear zone. Thus, deer accidents should be excluded from forensic investigations.

In addition, almost no correlation to design-related features can be made for crashes involving:

- A drunk driver.
- A driver who suffered a stroke, seizure, or other severe medical condition.
- A driver who fell asleep.
- A vehicle failure (e.g., blown tires), or objects falling from a moving vehicle (e.g., truck).
- Bicycles and pedestrians.

A final point regarding the identification of candidate sites involves the timeliness of the geometric information. Of the 17 at-grade intersection sites identified and visited, improvements had been implemented at 4 sites and construction was ongoing at 3 additional sites. At two sites, traffic signal control had been installed. At one site, turn lanes and signal control had been installed. At another site, turn lanes and signal control were being installed. An apparent road/shoulder widening project was affecting conditions at one site. Despite efforts to utilize the latest and best information available, geometric and traffic control changes are and will be implemented. If HSIS data and resources are used to identify candidate sites, it may be appropriate, prior to visiting the sites, to discuss whether subsequent changes have been, are being, or are planned to be made at the selected sites.

Availability and Quality of Site Data

Site geometric plans may not be available, or if they are, they may not reflect current field conditions. The quality may be poor. Yet, without plans as an available resource, more effort will be needed to gather the information from other sources, including field measurements.

Also, there is a demonstrated need to use individual hard copies of police accident reports. For some States, they may need to be requested from another section or another division of the DOT, or even from a different department. Moreover, specific reports may be missing. The delay in obtaining this needed information may adversely impact the schedule for producing a working prototype of the DRC.

Given that much of this analysis is driven by police accident reports, it should also be recognized that accident data are not always of a high quality. For example, location information is generally recognized as having a limited degree of accuracy, especially in rural areas on roads with no mile-marker system. With respect to information on selected Minnesota reports, there were errors regarding the direction of travel and north arrows. Some vehicles were evidently assigned to incorrect intersection approaches. In addition, several reports had missing diagrams and/or had sketchy narratives that did not lend themselves to causal assessment. For example, one narrative simply stated that vehicle #1 hit vehicle #2, without any further elaboration. This created difficulty with the preparation of a collision diagram for at least one site. Consequently, it is important to employ data from States that have the highest quality of police accident reports and computer-based accident record systems.

Finally, traffic data (e.g., ADT, turning-movement counts) are not generally available for rural intersections. For several of the 17 selected intersections in Minnesota, ADT information was not available for the side roads. The lack of data may hamper the team's ability to draw meaningful conclusions. Traffic volumes could affect or even substantially contribute to the crash problem. Consider one of the selected sites where a short bypass lane had been striped. Based on the observations completed in this study, all three members of the investigating team remarked about volume, large trucks, and speed. Unfortunately, data were not available for any of these variables. While there are application guidelines in the *AASHTO Green Book* and in the Minnesota design manual for full-width left-turn lanes on two-lane rural roads, the team could not verify whether the current conditions met or exceeded these application guidelines, due to the absence of turning-movement volume counts. If these data could have been obtained, it may have been possible to determine if the intersection warranted full-length left-turn lanes rather than bypass lanes. For subsequent field efforts related to forensic investigations at intersections, it is strongly recommended that provisions be made for gathering available traffic data or collecting new traffic data, notably turning-movement counts, vehicle-mix data, and spot speeds.

Perspectives on Multidisciplinary Team Members

Based on these investigations, it appears that a human factors specialist would offer unique insights that would not be generated by a highway designer, a traffic engineer, or an accident reconstructionist. For example, with respect to available intersection sight distance, the human factors specialist expresses this variable in terms of time. In general, highway engineers think in terms of distances. However, depending on the degree of experience with highway design, the human factors specialist may dwell on driver/driver interactions and attempt to establish the relative degree of fault. In addition, a human factors specialist may think in terms of driver-related mitigating measures and not potential roadway-design deficiencies.

In contrast, similar perspectives were shared by the traffic engineer/highway safety researcher and the traffic engineer/accident investigator. The latter had more geometric design experience and looked more at superelevation and drainage issues than the former. Yet, in general, the two groups generated similar observations and drew similar conclusions.

Effects of Environmental Conditions on Site Investigations

Several environmental conditions could affect the results of the site investigations. These factors include the ambient weather conditions and time period (e.g., season of the year, time of day).

At several sites in Minnesota, the wind chill was well below freezing during the field investigations. This tended to induce the team into quick judgments on the relative contributory effect of highway design features. At one location, the site was visited late in the day. Sunset precluded additional examinations. At both sites, more in-depth investigations may have led to different conclusions about the relative contributory effects of the highway design. It is highly recommended that forensic investigations be conducted during conditions that are conducive to field work. It might be appropriate to delay or postpone the site investigations until the weather conditions improve. In either case, forensic investigations cannot be expected to be conducted with 100-percent efficiency. Provision should be made for lost or down time in the field.

The season of the year in which the site is visited may also influence the results of the investigation. Highway safety researchers are well aware of the effect that seasonal changes can have on crashes. Intersections in agricultural areas may have almost unlimited intersection sight distances immediately after the crops have been harvested. However, prior to harvesting, the conditions may restrict available sight distance to less than minimum standards. In addition, crash data may indicate that the problem is seasonal in nature, due to a variety of factors, such as:

- Fluctuating traffic volumes in recreational areas, such as lakes and ski areas.
- Weather conditions (e.g., snow and ice in mountainous areas).
- East-west glare when the sun is at a particular angle in the sky during peak periods.
- Land use conditions (e.g., active produce stands during late summer seasons).
- Other environmental conditions (e.g., deer crashes in November).

While it is not possible to conduct all forensic investigations during the same time periods when the crash problems are manifested, the influence of time and seasonal variations should be considered when scheduling the site investigations.

Limitations in Translating Findings to Design Guidelines

Previous sections of this chapter have focused on the issues associated with actually conducting a multidisciplinary site investigation. Translation of the findings and insights of each investigation into general rules for the DRC knowledge base has yet to be discussed. It is possible that a field study could be completed according to the outlined procedures and not yield any useable results. Useable results are defined as those that provide information about a problem emphasis area and can be added to the knowledge base. This section describes several scenarios that could lead to a site investigation yielding no information for the knowledge base. These limitations should be understood before these costly investigations are conducted. Pitfalls to extrapolating findings into rules include the following:

- Limited number of data points.
- Inability to generalize findings.
- Inconclusive findings.
- Contributory factors beyond the control of the designer.
- Inability to translate findings into a CADD-compatible system.

Limited Number of Data Points

At one site, hypotheses were formulated about the potential contributions of geometric elements to the causes of crashes on the downgrade approach to a three-legged intersection with a bypass lane. If one can accept that this was truly a hazardous site and if the team concluded that the combination of the downgrade and the relative shortness of the bypass lane contributed to the rear-end crashes, then rules could be developed that would attempt to look for that combination of downgrade and bypass-lane taper and length design (assuming this information can be extracted from the CADD file). Yet, it is debatable that there may be other combinations, in which the bypass lane is slightly longer, but the taper is shorter, that are also potential problems. Alternatively, what about the situation where both the taper and bypass lane are longer but the downgrade is steeper? It should be recognized that this site investigation yielded one data point on a multidimensional figure. It is intuitively logical that there are other combinations that are also problematic. This approach will not yield a set of "threshold" conditions (i.e., a "switching" plane in three-dimensional space or a "warranting" curve in a two-dimensional graph). Consequently, only a subset of potentially problematic situations would be incorporated into the knowledge base from a single-site investigation.

Inability to Generalize Findings

One of the criticisms raised by selected State personnel who were interviewed, as well as some members of this research team, is the transferability of findings. For example, is a problem defined from an investigation of an intersection site with bypass lanes in Minnesota appropriate or applicable to other States? If bypass lanes are not generally implemented by another State, is the knowledge about problematic intersections with bypass lanes transferable? Alternatively, consider an intersection design that is "permissible" under design standards for a State "A" but not "permissible" for State "B." Will the findings from State "A" be transferable to State "B"? It should be recognized that selected State design practices may restrict the usefulness of selected knowledge for other States.

Inconclusive Findings

At one three-legged intersection site, a hypothesis was formulated as to possible roadway design-related causes of specific types of crashes. A large number of rear-end crashes involved a vehicle on the side road that had stopped at the stop sign, started to go, and then stopped again. Only by observing conditions and driving through the intersection several times did the team conjecture that the possible cause was related to vehicles turning left from the major roadway. However, there was insufficient information to conclude that this was the cause of these crashes. The narratives on the police crash reports did not possess the necessary level of detail. Moreover, the team did not have the capacity to interview the drivers who were involved. Consequently, the team could only offer educated guesses as to an explanation for this type of crash. It is highly likely that a proportion of these forensic investigations will yield inconclusive findings. This should be anticipated and factored into the cost proposal.

Contributory Factors Beyond the Control of the Designer

At one site, a large, unique billboard sign showing a large hamburger was present on the right side of a T-intersection in which the side road intersected to the left of the sign (see figure 11). Again, it was conjectured that the sign may have attracted the attention of the drivers involved in rear-end crashes with a vehicle turning left. This is a classic example of the situation in which the contributing factor, which in this case was the sign, is beyond the control of the highway designer. During the design process, objects outside the right-of-way are generally not considered. Moreover, the designer is not likely to change the design (e.g., increase the right-of-way) in anticipation that someone will place a sign at this intersection that will contribute to crashes. Hence, the site investigation may yield a conclusion, but it might be entirely related to an extraneous factor. As was the case with inconclusive findings, provision should be made for the expected result that some forensic investigations will yield knowledge that cannot be used in the DRC knowledge base.

Inability to Translate Findings Into a CADD-Compatible System

Another important issue to remember about these forensic investigations is that they may yield valuable knowledge that may not be readily useable within the context of IHSDM, because some lines and points within CADD may not have any attributes and may therefore not be interpretable or usable within CADD. Consider the intersection with bypass lanes. The pavement edge lines have no attribute data (i.e., they are not described by a set of critical points). Consequently, CADD currently has no way of recognizing that they define the edge of the travel way as opposed to the edge of the paved shoulder. Thus, the length of the taper, the width of the bypass lane, the proximity to roadside objects such as guardrails, and the length of the bypass lanes currently cannot be calculated from the CADD file. For this situation, a series of questions will need to be posed to IHSDM users in order for the DRC to apply logic that would assess the adequacy of bypass lanes properly. This limitation should be recognized and understood by FHWA when making decisions on emphasis areas.

Post-Investigation Involvement Development Team

To overcome the pitfalls listed in the previous section, the expert system development team must exercise a significant amount of engineering judgment. This team will be composed of the selected contractor team, which is likely to include the knowledge engineer(s) and a variety of people with expertise in design, highway safety, traffic engineering, human factors, accident reconstruction, and forensic investigations. FHWA staff would serve in the role of the advocate. The development team could also include additional "experts" retained as special consultants by the FHWA and other contractors supporting the development of the IHSDM. Members of the IHSDM Technical Work Group will provide the perspective of potential users by commenting on the results at various stages of the prototype development. The involvement of each member in constructing the knowledge base and judging the ultimate performance of the DRC is crucial.

Rules for Interactive Checklist Development

The type of rules that can be developed for the interactive checklist expert system will depend greatly on the forensic investigation findings. Each forensic investigation is likely to shed greater insight into the causal relationships between crashes and geometric features. Two issues must be resolved in translating these findings. The first relates to how the findings from one specific site can be generalized to apply to a wider variety of similar designs. The second relates to how the findings should be structured and incorporated into the interactive checklist. These issues are discussed in greater detail using an illustrative example from the Minnesota investigations.

Consider the intersection on the curve with the bypass lane and the offset crossroads with one leg intersecting at a skewed angle. A photograph of this site is shown in figure 14. The investigators made several observations about the relative contributions of the geometrics to the crash history. One observation was that the intersection sight distance from the perpendicular side road approach to the right was inadequate. A combination of large-diameter trees in this quadrant, the curvature of the major road, and the high speed of traffic could have made it difficult for drivers to perceive acceptable gaps in the traffic stream. The fact that the opposing, skewed side-street approach was offset by almost 31 m (100 ft) further taxed the driver's ability to make a judgment about whether it was safe to turn left. Besides searching for conflicting vehicles on the major road, the driver on the perpendicular side-road approach must also search for vehicles on the skewed approach, and if a vehicle is present, the driver must then make a judgment about whether the vehicle will enter the major road and adversely affect his or her ability to turn left.

In addition, at this intersection, it was observed that several drivers turning left onto the skewed leg of the intersection attempted the maneuver at a high rate of speed, and some cut the corner sharply. Frequently, left-turning drivers initiated the left turn far upstream of the intersection. During the short time that the forensic investigators were present, there were several conflicts in which a left-turning vehicle from the major road narrowly missed a vehicle turning right from the skewed approach. The investigators expressed an opinion that the combination of the skew of the one leg, the offset between the side road, the limited intersection sight distance, the horizontal alignment for the major road, and the speed of traffic on the major road all contributed to increasing the relative hazardousness of the intersection.

With respect to the first issue, i.e., generalizing the findings, the situation previously described combines a variety of geometric features. If the interactive checklist were developed such that the applicable questions were only for situations with similar geometrics, then the expert system would rarely pose these questions to the user. However, despite the uniqueness of this site, the same checklist items and expert system rules could be developed so as to be appropriate for other intersections that share some, but not all, similar aspects. From this example, checklist items could apply to the following types of generic intersections:

- Four-legged intersections with an offset between the intersecting side roads.
- Four-legged intersections with one skewed leg.
- Intersections on a horizontal curve, including three-legged intersections with the side road intersecting on the inside of the curve.
- Y-type intersections.

With respect to the second issue, which relates to the structure and incorporation of the findings into the interactive checklist, a series of interactive questions can be developed. For example, the following decision-tree logic could be developed from the forensic investigation of this site:

(1) Is the intersection on the inside of a horizontal curve? *If yes, go to 1.A. If no, go to 1.B.*

— (1.A) Is there sufficient intersection sight distance from the side-road approaches to the left and to the right? *If yes, go to 1.A.1. If no, go to 1.A.2.*

— (1.A.1) Does the expected average operating speed (as opposed to the design speed) on the major road justify consideration of a longer sight distance? For example, is the major approach on a downgrade such that average approach speeds will be higher? *If yes, go to 1.A.1.a. If no, go to 1.A.1.b.*

— (1.A.1.a) Can the roadside be redesigned and/or can sight obstructions be removed in the quadrant to provide a longer sight distance? *If yes, go to 1.A.1.a.i. If no, go to 1.A.1.a.ii.*

— (1.A.1.a.i) Issue the statement, "You may want to change the roadside design to increase sight distance for side-road approach on the inside of the curve," and then go to 1.A.1.b.

— (1.A.1.a.ii) Issue the statement, "You may want to consider reducing the degree of curvature to increase the intersection sight distance for the side-road approach on the inside of the curve," and then go to 1.A.1.b.

— (1.A.1.b) Will drivers on the major road be able to perceive and then safely and properly react to vehicles on the side road, given the degree of curvature and length of horizontal curve on the major road? *If yes, go to 1.A.1.b.i. If no, go to 1.A.1.b.ii.*

— (1.A.1.b.i) Go to 2.

— (1.A.1.b.ii) Issue the statement "You may want to consider changing the design to increase the sight distance from the major approach to the intersection such that drivers on the uncontrolled approach will be better able to detect the presence of an intersection. Intersection warning signs may be appropriate if the design cannot be improved," and then go to 2.

— (1.A.2) Can intersection sight distance be increased by obtaining and clearing additional right-of-way on the inside of the curve? *If yes, go to 1.A.2.a. If no, go to 1.A.2.b.*

— (1.A.2.a) Issue the statement, "You may want to consider increasing the right-of-way and removing obstructions to sight lines to increase intersection sight distance for the side-road approach on the inside of a curve," and then go to 2.

— (1.A.2.b) Issue the statement, "You may want to consider reducing the degree of curvature to improve intersection sight distance on the inside of the curve. Attention should also be given to appropriate signing," and then go to 2.

— (1.B) Issue the statement, "You may want to consider changing the design to increase intersection sight distance for the side-road approach on the inside of a curve," and then go to 2.

(2) Is the intersection a four-legged intersection? *If yes, go to 2.A. If no, go to 2.B.*

— (2.A) Is there an offset between the side-road approaches? *If yes, go to 2.A.1. If no, go to 2.A.2.*

— (2.A.1) Are the side roads sufficiently far apart that they will operate safely and efficiently as independent intersections? *If yes, go to 2.A.1.a. If no, go to 2.A.1.b.*

— (2.A.1.a) Issue the statement, "Two three-legged intersections should be assessed separately," and then go to 3.

— (2.A.1.b) Will left-turns from the opposing approaches on the major road "interfere" with each other? *If yes, go to 2.A.1.b.i. If no, go to 2.A.1.b.ii.*

— (2.A.1.b.i) Issue the statement, "You may want to consider revising the design to reduce the offset of the side-road legs," and then go to 4.

— (2.A.1.b.ii) Go to 4.

— (2.A.2) Go to 4.

— (2.B) Go to 4.

(3) Do one or both legs intersect at a skewed angle? *If yes, go to 3.A. If no, go to 3.B.*

— (3.A) Does the angle make it difficult for vehicles to turn, or will it adversely impact traffic operations and safety of the intersection? *If yes, go to 3.A.1. If no, go to 3.A.2.*

— (3.A.1) Issue the statement, "You may want to consider redesigning the intersection to create an angle closer to 90 degrees that will facilitate flow and enhance safety," and then go to 5.

— (3.A.2) Go to 5.

— (3.B) Go to 5.

(4) Is the intersection a three-legged intersection? *If yes, go to 4.A. If no, go to 4.B.*

— (4.A) Does the side road intersect at a right angle? *If yes, go to 4.A.1. If no, go to 4.A.2.*

— (4.A.1) Go to 5.

— (4.A.2) Does the angle promote safe turns to and from the skewed approach? *If yes, go to 4.A.2.a. If no, go to 4.A.2.b.*

— (4.A.2.a) Go to 5.

— (4.A.2.b) Issue the statement, "You may want to consider redesigning the intersection to create an angle closer to 90 degrees that will facilitate flow and enhance safety," and then go to 5.

— (4.B) Go to 5.

As illustrated by this example, the findings of the investigations can be translated into a decision tree to be applied within the interactive checklist expert system. As the DRC matures, it would be highly desirable to extract the data needed to answer these questions automatically from the CADD file. Then, the user would not need to be prompted with as many questions. Arguably, employing rules that have a more quantitative basis is also desirable for the DRC. Specifically, one of the last questions asks the user, "Does the angle promote safe turns to and from the skewed approach?" This question, as it is currently worded, requires the user to render a judgment as to what constitutes an acceptable angle for safe turns. Based on the survey of State practitioners, some thought below 75 degrees was unacceptable. Others thought that 60 degrees was the threshold. At least one individual thought 45 degrees was acceptable. Clearly, it would be useful to define criteria that would establish the threshold value that can be used as a guideline. Thus, while the qualitative aspect of an interactive checklist expert system allows a greater degree of flexibility, it also allows a much greater range of permissible solutions.

Rules for Automated Review Development

Before conducting any field investigations, the selected experts on the development team should recognize that their ultimate role is to establish the quantitative design (and possibly traffic) criteria that would identify the problem chosen for investigation. Following an expert systems approach, the translation of their findings into rules for the knowledge base is accomplished by evaluating the opinions, observations, experience, and consensus of team members. Thus, the actual design of the site(s) is only a starting point that provides one piece of evidence for the determination of design guidelines.

Again, the translation of the findings into rules can best be illustrated by an example. For the automated review to function as it has been described, rules must be written for the expert system to recognize specific situations and flag those locations. As discussed earlier, the rules can be very tight, which would tend to flag those locations that have a high degree of similarity with the site where the forensic investigation revealed that one or more design deficiencies contributed to crashes. With tight definitions of problem sites, flags will be raised only infrequently. Alternatively, the rules can be very loose, which would result in flagging locations that are only slightly similar to the original problem site. Loose rules would produce more flags than tight rules. Consider the offset, four-legged intersection with one skewed leg that was previously described. One set of tight rules for the expert system might include the following:

- If opposing three-legged intersections are offset by > 27 m (90 ft), but less than 61 m (200 ft), AND. . .
- If one (or both) side roads intersect at an angle < 70 degrees, AND. . .
- If the horizontal alignment near the intersection includes a horizontal curve with a degree of curve > 3 degrees AND a length of curve > 100 m (328 ft), AND. . .
- If the order (in terms of increasing milepoint on the major road) of the points of intersections is right leg then left leg (as opposed to left leg then right leg), AND. . .
- If the average operating speed (or design speed) on the major road is > 80 km/h (50 mi/h), AND. . .
- If the ADT on the major road is > 8,000 vehicles per day.

By comparison, a set of loose rules might include the following:

- If opposing three-legged intersections are offset by > 15 m (50 ft), AND. . .
- If one or both side roads intersect at an angle < 90 degrees, AND. . .
- If the order is right leg, then left leg, AND. . .
- If the horizontal alignment on the major road is not a tangent.

As can be seen, for the loose rules, neither traffic nor speed data are included in the criteria. Moreover, the loose rules do not specify a minimum degree of curvature or a minimum length of curve; they merely require that the horizontal alignment of the major road through the intersection not be a tangent. In addition, the numerical values for offset and for angle of intersection are more inclusive. For example, the tight rules would require the angle to be less than 70 degrees and the offset to be between 27 and 61 m (90 and 200 ft), whereas the loose rules would require the angle to be less than 90 degrees and the offset to be between 15 and 152 m (50 and 500 ft). Thus, the application of the loose rules would result in more flags being raised by the expert system.

As discussed in chapter 4, the developers should avoid over-specifying a problem using very tight rules that result in a flag never being raised. Conversely, under-specifying the situation using very loose rules results in a flag being raised so often for a minor issue that users become annoyed and lose faith in the credibility of the DRC.

When the work of the expert system development team is completed, the knowledge engineer and the FHWA will be presented with a report outlining the investigations team's conclusions and proposed design guidelines. If the development team cannot establish any design guidelines, then the knowledge engineer and the FHWA must determine if further investigations are needed, additional expert interviews should be conducted, or the attempt to define the particular problem should be abandoned. A flow chart that describes this process is found in chapter 9. If the team proposes design guidelines for a given problem, then the knowledge engineer must determine how to translate these rules into computer logic operating within CADD. Subsequently, the development team may be asked to review a prototype and comment on its ability to identify the situation according to their original intentions.

SUMMARY

This chapter presented the methodology and findings from 17 site investigations conducted by a multidisciplinary team in Minnesota. All sites were intersections of two-lane rural roads at or near horizontal or vertical curves. The team consisted of a local traffic engineer, a human factors specialist, and a highway safety researcher. The sites were identified using the HSIS and data from an earlier research effort.[26]

Collision diagrams prepared for each site prior to the field visit were found to provide valuable information. Problem locations included T-intersections with bypass lanes; an intersection at an isolated, sharp curve; skewed intersections; and T-intersections on horizontal curves. Some illustrative design guidelines were presented, based on the site observations.

The findings of the investigations could benefit the knowledge base for the automated review, but little information could be gained for the interactive checklist feature. The advantages of this method include the potential to develop geometric specifications, the benefits of a synergistic group effort, and the attempt to "learn from our mistakes." The relative disadvantages include a narrow focus, limited sample size, elevated cost, and confounding influences. Recommendations outlined the identification of candidate sites, the availability and quality of site data, the composition of the team, and the effects of environmental conditions. Five potential pitfalls that may be encountered while attempting to translate the findings into design guidelines were reviewed. Finally, this chapter discussed the involvement of the expert system development team after completion of the investigations, including their efforts to translate findings into elements of the knowledge base.

CHAPTER 7. LITERATURE REVIEW RESULTS

A tremendous amount of research has been conducted to examine the relationship between geometric design and safety on two-lane rural roads. The purpose of this effort was to determine the worth of published research findings for application to the knowledge base of the DRC. Because the DRC will be a design tool operating within a CADD-compatible environment, research of value to this study must either: (1) indicate design features or situations that may be safety deficient, or (2) provide quantitative design guidelines for such situations. For example, studies have examined such features as intersection sight distance, lane width, and vertical and horizontal curvature combinations. The first type of research result may indicate situations that could be overlooked by the designer, such as guardrail restricting the sight triangle, or driveways in proximity to an intersection. These studies could be used to provide a first pass at the content of the interactive checklist. Quantitative design guidelines, or recommendations reported in geometric design units of measure, are in a form that could apply to the automated review. Both types of results, however, require subsequent analysis and/or specification before being added to the knowledge base. Consequently, there is value to be gained from reviewing research and extracting key findings, as the first in a series of steps that ultimately leads to the development of the expert system.

The literature review revealed that safety-related research on two-lane rural roads generally produces results in one of the following formats:

- **Accident prediction equations or graphical relationships.** The accident rate or frequency is predicted based on a set of independent and dependent variables. For example, the predicted number of accidents on a two-lane rural-road section may be a function of ADT, alignment, roadside hazards, and topography. The equation is calibrated to a pattern of observed data and may be validated with data from other studies.

- **Design guidelines or warrants for cost-effective improvements.** Design guidelines may be presented in either qualitative or quantitative form. Frequently, the purpose of this type of study is to examine the adequacy of current design policy, such as sight distance or turning radii. Qualitative recommendations state something like, "Steep sideslopes on the outside of horizontal curves to the left should be avoided." Conversely, results reported quantitatively would state, "Sideslopes of 4:1 or steeper should be avoided on the outside of horizontal curves to the left and greater than 10 degrees." Studies on cost-effectiveness offer guidelines for optimal design, based on a set of conditions that should be present to justify the allocation of funds. Conditions include traffic volume levels, turning movements, percentage of truck traffic, or accident history.

- **Comparative analysis of the safety effects of isolated design features.** Accident rates are examined at locations similar in design and traffic volumes, but with the exception of one feature (e.g., lane width). For example, one study compared accident rates along roadways with 3:1 sideslopes versus similar sections of roadway having 7:1 sideslopes.[29] Another common example is a study that examined the effects of lane and shoulder width on safety. Lane width was held constant while the shoulder width was varied.[30] The results of these types of studies are frequently reported as a graph, with accident rate on the vertical axis and the isolated design feature on the horizontal axis.

- **Accident reduction factors.** Before-and-after studies generally present accident reduction factors based on a reduced number of accidents following some alteration of the design. Before-and-after studies were not reviewed in this research, since this specific task comprises a separate FHWA contract.

Research results with potential application to the DRC must specifically examine one or more elements of design and their relationship to safety. Study findings could potentially provide data for the first pass at the knowledge base by providing insights and verifying the findings derived from other knowledge acquisition methods. The utility of research findings and the level of effort related to using this knowledge source is discussed in the final section of this chapter. Studies reviewed in this chapter are classified according to their "quantitative" (geometric design units of measure) or "qualitative" (identification of problematic design situations or features) recommendations. For example, a study that isolates a single design feature but does not provide numerical design guidelines is classified as a qualitative finding.

At the April 1996 IHSDM workshop, safety audits were identified as a second source of literature with potential application to the DRC knowledge base. A safety audit is a means of checking the design, implementation, and operation of road projects against a set of safety principles, for the purposes of accident prevention and treatment. This practice has been adopted in Australia, New Zealand, and Great Britain. This "means of checking" is outlined by a safety-audit checklist containing the specific elements and potential problem areas to be reviewed. Safety-audit literature was obtained to gain a basic understanding of the procedure. Checklists were obtained from each of the three countries, to determine the suitability of checklist items for application to the knowledge base.

The first section of this chapter describes the methods employed in the literature search and the criteria for including research findings in this report. The second section presents a sample of research findings believed to have potential application to the DRC knowledge base. This section is divided into three subsections: (1) Quantitative Design Guidelines From Research Studies, (2) Problematic Design Situations/Features Reported in the Literature, and (3) Findings From Safety-Audit Literature. The first two subsections are purely results oriented; findings are reported in tabular form, with limited descriptive text. In the third subsection, an introduction to safety audits is provided, since the concept is relatively new in the United States. Data provided by safety-audit checklists are examined to conclude the second section. The third section summarizes the relative advantages, disadvantages, and level of effort required to use the literature to construct the knowledge base. The final section of this chapter discusses the implications of applying research findings to the DRC.

METHODOLOGY

The scope of literature reviewed was limited to safety-related research on two-lane rural roads. Due to the extensive amount of work performed in this area, the bounds of this topic required the review of a very large number of studies. Two factors narrowed the scope of results reported in this chapter: (1) the exclusion of before-and-after studies, which are the topic of a separate FHWA study; and (2) the exclusion of studies whose recommendations do not relate to any particular design feature. In most cases, it was necessary to review only the report's abstract, conclusions, and recommendations to make this distinction. In addition, only research performed in the United States and Canada was reviewed. For the purposes of this study, the literature search was not intended to be comprehensive, but thorough enough to demonstrate the quality of data derived from published findings and to generate recommendations for further work, if deemed beneficial. Nearly all research findings presented in this chapter were published in either NCHRP reports or FHWA reports, or were summarized in Transportation Research Records.

Once the selection process to decide which studies had potential application to the DRC knowledge base was completed, the literature was further categorized. Study results were found to consist of either quantitative design guidelines or problematic design situations or features identification. The reporting method for both types of studies involved first categorizing the finding into one of four areas: horizontal alignment, vertical alignment, cross section, or roadside. Two items were extracted from each report: design guidelines, and the substantiation of the findings (i.e., sample size, lane miles, or methodology). These data were then summarized in tabular form. For studies not offering quantitative guidelines, but still identifying a problematic situation or feature, three items were extracted: a description of the problem, the magnitude/severity of the related accident problem, and the design specification (if any).

Safety-audit literature was reviewed for two purposes: (1) to explain the concept and procedures employed by those countries who perform safety audits, and (2) to examine the utility of safety-audit checklists for the DRC knowledge base. A TRIS search with the keyword "safety audit" yielded limited results. Safety audits are a relatively new idea and are largely unfamiliar to the research community in North America. Literature on safety audits was obtained through transportation authorities in Australia and New Zealand. The documents outline the philosophy, potential applications, and procedures for conducting safety audits. In addition, checklists were included with this material. A short interview with a consultant in Great Britain who performs safety audits provided additional background. A report of an actual safety-audit project and the associated checklist was obtained from this consultant. Two final sources of information on safety audits were provided by the Institute of Transportation Engineers (ITE) report, *Road Safety Audits*, and the text, *Safer Roads: A Guide to Road Safety Engineering*.[31,32]

FINDINGS: ACCIDENT RESEARCH AND SAFETY-AUDIT LITERATURE

Recommended Design Guidelines From Research Studies

In proportion to the total number of studies conducted on two-lane rural roads, research results that ultimately recommend numerical design guidelines are extremely scarce. The criterion for these guidelines is that they must be stated in geometric design units of measure. This requirement eliminates studies that report accident warrants for geometric improvements, accident rates at sites with an isolated design feature, or accident-reduction factors. Only eight such reports were identified in this effort. These studies are summarized in table 8.

As shown in table 8, some design recommendations are based on ADT, percentage of trucks, design speed, and operating speeds of vehicles. Several recommendations provide guidance for the reconstruction of horizontal and vertical curves. Other recommendations in table 8 simply state what design values should be avoided. Recommendations relative to sideslope values also indicate that conflicting conclusions may be derived from studies of the same design feature. Many guidelines are provided by TRB Special Report #214, "Practices for Resurfacing, Restoration, and Rehabilitation."[(34)] Some States have adopted the findings of this report as the design standards for projects constructed in the 3-R program. The issue on geometric design standards versus 3-R standards will need to be addressed in the Policy Review Module.

Problematic Design Situations/Features Reported in the Literature

Much of the research examining the relationship between geometric design features and safety identifies a problem, but does not define the problem in geometric design units of measure. Many studies correlated an isolated design parameter (e.g., lane width, horizontal curve, sight distance) to the number of accidents at sites in various States, to determine a relationship of the parameter to accident experience. Table 9 presents these findings from the accident research literature. It was suggested by some studies that there is a need for better data quality and consistency between States. One such report, *Accidents on Rural Two-Lane Roads: Differences Between Seven States*, concluded by stating that data from different States should not be pooled together, unless it is ensured that data sets are quantitatively and qualitatively similar.[(38)]

The studies in Table 9 indicate that lane width, tangent length, degree of curvature, sight distance, clear zone (road recovery distance), and sideslopes are among the variables influencing the probability of accidents.[(39,40)] Some intuitive implications may be derived, but there was no detailed specification of the problem. The problematic design situations cited lack the quantitative data necessary to present conclusive correlations between an actual number of accidents and the interaction of other roadway design parameters. However, it is noted that in most studies, multiple-regression analysis was used to determine the effects of different roadway parameters (e.g., degree of curvature, tangent length) on the number of accidents.

Table 8. Recommended design guidelines from research studies.

Design Feature	Guideline	Substantiation
Horizontal Alignment	1. For volumes above 1,500 ADT, a minimum shoulder width of 1.8 to 2.4 m (6 to 8 ft), depending on functional class. 2. Lanes 3.4 or 3.7 m (11 or 12 ft) wide may be undesirable on roads with lower design speeds (80 km/h [50 mi/h] or less).	Analysis of 6,598 km (4,100 mi) of two-lane road in 10 States, supplemented by data bases of 86,900 roadway km (54,000 roadway mi) in 3 other States. (Zegeer et al., NCHRP Report 362, 1994)[30]
	Central angles greater than 30 degrees may result in safety problems. Central angles greater than 45 degrees should be avoided whenever possible.	Analysis of 10,900 horizontal curves in Washington State, supplemented by 3 Federal data bases. (Zegeer et al., FHWA-RD-90-021)[33]
	Where the design speed of a curve is more then 24 km/h (15 mi/h) below the 85th percentile speed of approaching vehicles, and traffic volume is greater than 750 vehicles per day, the curve should be considered for reconstruction (assuming that improved superelevation cannot reduce this difference below 24 km/h [15 mi/h]).	Case studies of design practices and review of current knowledge about relationships between geometric design and safety. (TRB Special Report 214)[34]
	1. The maximum increase in curvature between curves 4.8 km (3 mi) apart or less should not exceed 3 degrees. 2. In compound geometric features, horizontal curves exceeding 3 degrees should be avoided. 3. Reverse curvature should not be used in any compound feature where sight distance is restricted.	Group of 21 experienced designers participated in a discussion and rating of hazardous locations based on violation of driver expectancy. (Messer et al., FHWA-RD-81-037)[35]
Vertical Alignment	Top priority should be given to roadside hazard modification on curves greater than 6 degrees on downhill grades greater than 2 degrees.	Analysis of 300 fatal-crash sites with 300 comparison sites (Wright and Robertson, IIHS Report, 1976)[36]
	Vertical curve flattening should be considered where: 1. Hill crest hides an intersection, sharp horizontal curve, or narrow bridge; 2. ADT is greater than 1,500 vehicles per day; and 3. Design speed of the curve is more then 32 km/h (20 mi/h) below the 85th percentile speed of vehicles on the crest.	Case studies of design practices and review of current knowledge about relationships between geometric design and safety. (TRB Special Report 214)[34]

Table 8. Recommended design guidelines from research studies (continued).

Design Feature	Guideline	Substantiation
Combinations of vertical and horizontal alignment	The combination of horizontal curves with a radius of less than 457 m (1,500 ft) and gradients more than 4 percent should be avoided.	N/A (Lay, *Handbook of Road Technology*, 1986)[37]
Cross Section	1. No accident reduction results from widening lanes from 2.7 to 3.0 m (9 to 10 ft). 2. For lane widths of 3.4 or 3.7 m (11 or 12 ft), shoulders of at least 0.9 m (3 ft) have significant effects. 3. No apparent safety benefit of increasing total roadway width above 9.1 m (30 ft) or lane width from 2.7 to 3.0 m (9 to 10 ft).	Analysis of 6,598 km (4,100 mi) of two-lane roads in 10 States, supplemented by data bases of 86,900 roadway km (54,000 roadway mi) in 3 other States. (Zegeer et al., NCHRP Report 362, 1994)[30]
	1. Recommended minimum lane and shoulder widths based on running speed and design year ADT (see table 9). 2. Recommended bridge widths for bridges less than 30.5-m- (100-ft-) long based on width of approach lanes and design year ADT (see table 10).	Case studies of design practices and review of current knowledge about relationships between geometric design and safety. (TRB Special Report 214)[34]
Roadside	Sideslopes of 5:1 or flatter are needed to significantly reduce rollover accidents.	Analysis of 2,858 km (1,776 mi) of two-lane roads in three States. (Zegeer et al., FHWA-RD-87-008)[29]
	Flatten sideslopes of 3:1 or steeper at locations where run-off-road accidents are likely to occur.	Case studies of design practices and review of current knowledge about relationships between geometric design and safety. (TRB Special Report 214)[34]

In a Kentucky study entitled, "The Effect of Lane and Shoulder Widths on Accident Reduction on Two-Lane Rural Roads," the effects of various lane and shoulder widths were analyzed for 17,000 accidents along 25,659 km (15,944 mi) of roads.[46] The study concluded that the number of run-off-road and opposite-direction accidents were higher than other accident types. As lane and shoulder width increase, accident rate was observed to decrease. Lane-width increases were more effective in accident reduction than shoulder-width increases. The study also found that run-off-road and opposite-direction accidents were associated with narrow lanes and shoulders. However, the results from this study and others continue to differ regarding the "optimal" shoulder width. For ADT ranging from 3,000 to 5,000 vehicles per day, this study and others support shoulder widening as the most effective approach for reducing accident rates. Table 10 highlights the findings of safety improvements frequently cited in the literature.

Table 9. Problematic design situations cited in the literature.

Specific Situation	Description of Problem	Magnitude/Severity of Related Accident Problem	Specification of Geometric Design	Cited
Horizontal Curves Following Short and Long Tangents	For two-lane rural roads, accident rates on horizontal curves are 1.5 to 4 times the accident rates on tangent sections.	- As degree of curvature increases, accident rates increase. - Curves with short and long approach tangents have higher accident rates. - Short approach sight distance for increasing degrees of curvature experience increased accident rates.	None provided.	Fink et al., TRR 1500, 1995[46]
Horizontal Curvature	Curves with degree of curvature ≥ 10° have pronounced accident rate increases. Increases in roadway widths of 6.7, 8.5, 10.4, and 12.2 m (22, 28, 34, and 40 ft) reduce accident rate.	For various ADT and road widths, accident rates increase when degree of curve and curve length increases.	None provided.	Zeeger et al., TRR 1356, 1992[47]
Side Friction on Horizontal Curves	Achieving AASHTO consistency in horizontal alignment design for side-friction demand (f_{RD}) versus side-friction assumed (f_R).	The point at which side-friction demand exceeds side-friction assumed corresponds to the average accident rates for fair design.	$f_{RD} > f_R$, for accident rates ≥6.0	Lamm, et al., TRR 1303, 1991[48]
Crest Vertical Curves	Intersections and other geometric conditions within the limited sight-distance sections of crest vertical curves have increased accident experience for increased volumes.	None provided.	None provided.	Urbanik II et al., TRR 1208, 1989[45]
Narrow Lanes and Shoulders	Lane width ≤ 2.7 m (9 ft) (¼ of U.S. mileage). Shoulder width ≤ 1.2 m (4 ft), (⅔ of U.S. mileage). No shoulders ~ 11.5 percent of U.S. mileage. Estimated U.S. mileage is 5 million km (3.1 million mi).	Low-volume (< 2,000 ADT) roadways with narrow lanes and/or shoulders have higher accident rates.	None provided.	Zeeger et al., NCHRP Report 362, 1994[44]
	Single-vehicle run-off-road fixed-object and rollover accidents are most related to lane and shoulder widths and roadside characteristics. 59.5 percent of U.S. two-lane rural roads have shoulder widths ≤ 1.2 m (4 ft).	Accident rates increase for two-lane rural roads with narrow lane and shoulder widths.	≤ 3-m (10-ft) lane width and no shoulders appear to be problematic. No other design features considered	Zeeger et al., TRR 1195, 1988[42]
Steep Sideslopes	Run-off-road fixed-object accident experience increases at locations with steeper sideslopes.	None provided.	None provided.	Zeeger et al., TRR 1195, 1988[43]

Table 10. Safety improvements frequently cited in the literature.

Category	Specific Improvement
Vertical Alignment Change	Flatten vertical curve. Reduce grade(s).
Horizontal Alignment	Increase curve length. Reduce degree of curvature. Improve superelevation.
Cross Section	Widen lanes. Widen shoulders. Add shoulders. Flatten cross slope on pavement and shoulder.
Roadside	Remove and/or relocate fixed objects. Flatten side or back slope. Install guardrail, crash attenuation devices.
Sight Distance	Improve sight distance through the inside of horizontal curves. Improve sight distance over the crest of vertical curves. Improve intersection sight distance.
Intersections	Add left-turn lanes. Add right-turn lanes. Add traffic signal controls.

Findings From Safety-Audit Literature

Introduction to Safety Audits

Safety audits have an objective similar to that of the IHSDM: to strive for accident *prevention* as opposed to accident *reduction*. A safety audit is a "formal examination of an existing or future road or traffic project, or any project which interacts with road users, in which an independent, qualified examiner looks at the project's accident potential and safety performance."[(47)] Highway designers and traffic engineers have traditionally performed some type of check to review the safety level of an existing site or design. The two major differences incorporated by safety audits are the following:

- The audit is performed as a discrete phase by persons independent of the designer, and it is restricted to road safety issues.

- An institutional requirement defines exactly how the audit is conducted and a report is prepared.[(32)]

Safety audits function to identify "preventable accident-producing elements (such as inappropriate intersection layouts) at the planning or design stages, or by mitigating the effects of remaining or existing problems by the inclusion of suitable accident-reducing features."[48]

In 1987, the Department of Transport in Great Britain set a goal to reduce accident casualties by one-third by the year 2000.[47] Safety audits began to gain larger acceptance, resulting in published guidelines in the United Kingdom in 1990.[50] Australia and New Zealand soon followed with formalized procedures established in the early 1990s.[47,51] Several regions in these countries mandated that safety audits be performed annually on a minimum number of projects, a percentage of the existing road system, or on all projects exceeding a certain cost.[31]

A safety audit is intended to be applied at any one of the following five stages:

- **Stage One: Feasibility.** Analysis of the project scope includes choice of route, impacts on the existing network, selection of design standards, and continuity of route.
- **Stage Two: Layout or Preliminary Design.** The audit is performed after the draft plans are completed. Considerations include: horizontal and vertical alignment, sight lines, intersection layouts, lane and shoulder width, and departure from standards.
- **Stage Three: Detailed Design.** Typical features reviewed include: pavement markings, signing, delineation, lighting, intersection details, clearance (relative to roadside objects), and guardrail.
- **Stage Four: Pre-Opening.** Before the project is opened to traffic, a field visit is conducted to ensure that the construction has not varied from the plans and that nothing has been overlooked. Both day and night reviews are suggested, and if possible, dry and wet condition reviews as well.
- **Stage Five: In-Service.** Segments of the road network are examined to identify any safety-related deficiencies.[32]

Tasks outlined in Stages Two and Three are strikingly similar to those envisioned for the DRC. Safety audits are "not simply the evaluation of each (design) element, but also of the interaction between the elements and how these will be perceived and negotiated by the users."[49] Thus, the DRC (and the IHSDM overall) could be viewed as an attempt to incorporate the safety-audit philosophy and process into CADD-compatible software.

A safety audit is generally conducted by at least two individuals with experience in traffic engineering, design, or another applicable field.[32] A site visit is an essential element for appraising the layout of the existing design and the traffic characteristics of the roadway. The process is generally assisted by a checklist of items to be reviewed. The checklist only serves as a guide and is not the entire basis of the audit. Because each site is unique, dependence on the checklist alone can result in important issues being overlooked.[49] Safety-audit checklists were obtained from the United Kingdom, Australia, and New Zealand, to determine their worth to the DRC knowledge base.

Findings From Safety-Audit Reports and Checklists

A copy of a safety-audit report completed by a consultant in London, England, includes the completed checklist used to review the road plan. The project was located at an urban Y-intersection controlled by a roundabout (circle) and included a short distance of the road in each of the three directions. The audit was completed at the detailed-design stage. Checklist categories include bicycle facilities, parking, bus facilities, pedestrian facilities, traffic signals, junctions, and general issues. Checklist items consist of qualitative questions such as, "Is the provision of guardrails adequate?" or "Are road sight lines adequate?" or "Are lane widths adequate?" These items are primarily applicable to the interactive checklist function of the DRC, because the audit report does not provide any further specification in geometric design units of measure. It only evaluates the features as "adequate" or "proper." Also, design recommendations for cited problem areas are purely qualitative. An example is, "The alignment should be reviewed and modified to create a smoother horizontal curvature." It should be noted that the checklist was completed for an urban project (the consultant had not performed any audits on rural roads), and many checklist items did not apply to two-lane rural roads.

The "Stage Three: Final Design" checklist used by Transit New Zealand contains a set of issues to be considered.(51) The checklist categories include: horizontal and vertical alignment geometry, typical cross sections, roadway layout, the effect of departures from standards or guidelines, and sight distance. Again, the items do not provide any specification of problem areas, only the general areas to review or consider. Example checklist items are, "Check that the horizontal and vertical design of the road fit together comfortably," and "Are there any approved departures from standards which affect safety?"(51)

The safety-audit checklist published by AUSTROADS, an Australian association of road transport and traffic authorities, provides separate checklists for each of the five stages.(47) The checklist items are also written in the form of issues to be considered, similar in format to New Zealand's checklist. Examples of checklist items for "Stage Three: Detailed Design" include, "Check that railway crossings, bridges, and other hazards are conspicuous," and "Are lane widths and swept paths adequate for all vehicles?"(47) The AUSTROADS Stage Three checklist is provided in appendix D.

Safety-audit checklist items for this study are written as issues to be considered and do not provide insight as to the specific guidelines that cause a design feature to become problematic. The checklists only attempt to provide a complete set of general items (depending on the stage) that should be reviewed during a safety audit. Since the checklists are not particular to urban or rural roads or highways versus local streets, the checklist items are intentionally vague so that they are not duly constrained. It is up to the persons performing the safety audit to determine on a case-by-case basis whether the feature is potentially problematic.

ADVANTAGES, DISADVANTAGES, AND REQUIRED LEVEL OF EFFORT

At the beginning of this chapter, study results were categorized into four general areas. The results were classified on the basis of the format being either quantitative (written in geometric design units of measure) or qualitative (identification of problematic design situations or features only). The primary advantage of quantitative data is the potential for application to the automated review of the DRC. Problems are specified to a level of detail that could eventually be translated to flag elements within a CADD-environment. Qualitative results are more applicable to the interactive checklist functions. Results could be used to generate checklist items, to help structure expert interviews, and to verify the rules developed in other knowledge acquisition methods. A second advantage of the literature over other knowledge acquisition methods is the increased sample size. The design criteria are constructed based on a "greater than one" sample size of sites. Other sources of knowledge (site investigations, expert interviews) may develop specifications based on a small sample size of sites or expert opinions. Substantiation of rules is well defined in research through an examination of the study methodology or sample size. Substantiation of a rule is not well defined in site investigations or expert interviews. A third advantage of the literature review is that report authors may be identified as having expertise in a particular area (e.g., safety effects of sight distance, lane width, vertical curvature) and contacted for interviews.

The primary disadvantage of a literature review is that research findings require significant manipulation, and possibly extrapolation. Accident research findings may be best utilized as an initial source of information, later refined and enhanced through other knowledge acquisition methods. Few studies present information that can be directly applied (i.e., without further refinement) to benefit the knowledge base for the automated review. Studies of the relationship between geometric design and highway safety are plentiful, but very few present numerical criteria needed to perform an automated review within CADD. Design recommendations could be derived from some studies, if threshold values (e.g., minimum accident frequencies) for safety were defined. Due to the subjective nature of this task and its implications, attempting to quantify a level of safety based on a threshold accident rate or frequency has been avoided by most researchers.

Another disadvantage, and one that involves all knowledge sources, is that of problem identification (see chapter 4). There must be some criteria for including research in the knowledge base, and this may become an impediment. If research findings are to be applied to the DRC knowledge base, associated questions include:

- Should a study performed in only one State qualify?
- What is an adequate sample size?
- What are the accident thresholds that separate desirable and undesirable design?
- Could the results be manipulated to produce either checklist items or design guidelines?

A final constraint associated with research findings stems from the design standards commonly applied to projects on two-lane rural roads. For these projects, States often have "3-R" (Resurfacing, Restoration, and Rehabilitation) or "Preservation" standards. In most cases, these standards are less restrictive than those found in the *AASHTO Green Book.*[9] As mentioned in chapter 2, the *AASHTO Green Book* is the basis for the Policy Review Module.

Future efforts may include the incorporation of 3-R standards, so that a user would be able to choose the set of appropriate design standards for the project. Design guidelines generated from research studies must be compared to AASHTO or a State's 3-R standards, to avoid a confusing overlap. In other words, the DRC should attempt to augment a policy review and not reanalyze the same features. The development team for the DRC, in close coordination with developers of the Policy Review Module, should work to avoid redundancy or contradiction between modules of the IHSDM.

Safety audits, while similar in principle to IHSDM, offer little information as to geometric design units of measure or the identification of potential problem areas. Safety-audit checklists are as yet generic to urban versus rural, or two-lane versus multilane scenarios. The checklists obtained did provide a general series of issues to consider, but they did not offer any evidence that problem areas could be derived from further analysis. Safety-audit checklists could be used as a starting point for developing the interactive checklist feature of the DRC. Safety-audit checklists, however, appear to offer few advantages for the knowledge base to be used to construct the automated review program.

Based on the findings of this research, literature on the relationship between safety and geometric design should be used to supplement the findings from other knowledge acquisition methods. Research findings may be used to generate ideas for checklist items, develop problem emphasis areas, or structure expert interviews. The literature may also be used to confirm or expand upon the parameters that describe a safety-deficient situation. Directly applying research results to the DRC, even where quantitative design guidelines are given, requires further manipulation and extrapolation by a group of experts to translate the data for the DRC. Safety-audit checklists may provide assistance during the first pass at the knowledge base for the interactive checklist, but such checklists also need to be manipulated by the development team to be applicable to two-lane rural roads. Thus, the literature alone is not expected to result in actual checklist items or rules for the knowledge base, but may prove beneficial in combination with other sources.

IMPLICATIONS FOR DEVELOPING THE DRC KNOWLEDGE BASE

It is estimated that a very limited number of studies offer quantitative design guidelines that are sufficient for direct translation to heuristics for the automated review function of the expert system. Research results could serve as an initial source of knowledge, which can be expanded by knowledge gained from expert interviews or site investigations. A significant amount of research has attempted to define the relationship between geometric design and safety, but rarely does this result in the definition of guidelines separating desirable and undesirable designs. Since the automated review must make such a numerical distinction, both qualitative and quantitative research results require further manipulation before being included in the DRC knowledge base. The application of research findings should, therefore, be limited to: (1) generating checklist items and problem emphasis areas for the first pass at the knowledge base, and (2) confirming or questioning the expert system rules developed in other knowledge acquisition methods.

The findings of this effort should not be construed to mean that all literature has only a supplementary role within the IHSDM. The scope of this study concerned the application of research findings to the DRC, corresponding to its proposed application as a design review tool.

As discussed previously, the integration of the DRC in CADD-compatible software imposes severe limitations on the content and format of useful knowledge. Current and future modules of the IHSDM may potentially utilize research findings for other functions. For example, research into the cost-effectiveness of design improvements, or studies of accident reduction factors may provide information for a cost/benefit or accident analysis module. In addition, two significant bodies of literature were not reviewed in this study: literature pertaining to tort liabilities, and before-and-after studies, which are currently under evaluation in separate FHWA studies. Other researchers may conclude that these materials are beneficial to the DRC or the IHSDM.

Safety-audit literature potentially offers benefits to the DRC interactive checklist function, but little can be gained for the automated review. The issues to consider in the checklists could help generate checklist items that should be incorporated into the DRC. Since the checklists are not specific to rural or urban areas, further manipulation would have to be performed by the development team to focus the items on two-lane rural roads. The principles of conducting a safety audit are very similar to those of the IHSDM. If safety audits were accepted as standard practice in the United States, they might have further application to the DRC. Documented safety audits, in which the safety-deficient problems are explicitly specified, may provide knowledge in a format that does not otherwise exist.

SUMMARY

This chapter examined the use of literature to develop the knowledge base for the DRC. The scope of the literature review included studies that examined the relationship between safety and design features, as well as material pertaining to safety audits. Study results were classified as either quantitative or qualitative. Quantitative results were those in which the researchers provide design guidelines in geometric design units of measure. Qualitative results provided a description of a problematic design situation or feature. The number of quantitative results was much smaller than the number of qualitative results. A brief history of safety audits was reviewed, and checklists used to perform safety audits were examined for application to the DRC. The advantages of using the literature to develop the knowledge base include the incorporation of quantitative findings, an increase in the sample size, and the identification of additional experts. The primary disadvantage of the literature is the significant amount of manipulation and extrapolation required to translate the findings into rules, or heuristics, for either the interactive checklist or the automated review features of the DRC expert system. Other disadvantages include the need to develop a selection criterion for research studies, and the potential for overlap with the Policy Review Module. A literature review was recommended as an initial source of knowledge and subsequently a supplementary source for other knowledge acquisition methods. This method could be used to generate data for the first pass at the knowledge base and to confirm or question the results obtained in other knowledge acquisition methods.

CHAPTER 8. HIGHWAY SAFETY IMPROVEMENT PROGRAMS: REVIEW RESULTS

The objective of the effort described in this chapter was to assess the value of information derived from three sources: (1) interviews with State and local traffic engineers, (2) documentation of projects funded by a State's highway safety improvement program (HSIP), and (3) analysis of checklists used by designers. The basic premise was that problem areas might be identifiable through a review of the types of safety improvement projects constructed in a State over a given year. The funding allocation to specific types of projects may indicate the type of improvements receiving priority, because not all candidate projects may be programmed in a given year.

Safety improvement projects completed on two-lane rural roads fall into one of two categories: (1) improvements completed as part of the State or Federal HSIP, and (2) improvements made during a reconstruction or 3-R project. HSIP projects are completed with Federal funding through the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), which directs 10 percent of a State's Surface Transportation Program (STP) funds to safety projects. States are therefore required to complete an HSIP annual report for submission to the FHWA. HSIP projects occur at spot locations where a cost-effective treatment is applied to mitigate (a) specific type(s) of crash pattern(s).

This research revealed that most safety improvements are *not* made through the HSIP. More frequently, they are implemented as part of projects to improve the pavement surface or roadway capacity. Safety-related improvements may include guardrail improvements, roadside obstacle removal, or the addition of left-turn lanes. These non-HSIP projects are usually referred to as either capital, 3-R, or reconstruction projects. The work generally occurs along a corridor from one to several miles in length. Unlike the HSIP, these projects are not documented in an annual report. Therefore, telephone and in-person interviews with traffic engineers in seven States were conducted to examine local perspectives on safety improvements and the type of information available on non-HSIP projects. In addition, the traffic engineers were asked to discuss the design situations that they felt were most problematic, as well as the potential corrective actions for those situations. Thus, for the purposes of this report, the knowledge source "HSIP" generally refers not only to HSIP-funded projects, but also to any projects where highway and intersection improvements are made in an effort to increase safety. The use of HSIP also encompasses the knowledge of traffic engineers and designers involved in projects on two-lane rural roads.

The first two sections of this chapter are divided into four subsections: telephone interviews, in-person interviews, HSIP documentation, and design checklists. The first section of this chapter describes the methodology of each task. The data and information obtained from each of the four sources are presented in the second section.

A variety of problematic situations were identified through the interviews. The individuals interviewed also provided a wealth of information about the current process of selecting, scoping, and designing projects on two-lane rural roads. This information, while outside the scope of the original objective, has important implications for the eventual implementation of the IHSDM and is therefore included in the second section.

In the third section, the advantages and disadvantages of extracting knowledge from these sources are outlined. The lessons learned from this task and relevant implications for the DRC are discussed in the final section.

METHODOLOGY

Telephone Interviews

State DOT personnel were contacted in Florida, Michigan, Minnesota, New York, Oregon, Pennsylvania, and Wisconsin. These States are considered to have some of the best-organized and most aggressive HSIP's in the country. Approximately eight individuals were interviewed in each State. Table 11 lists the names and departments of persons contacted for this study. The primary contact in each State was a member of the traffic safety department in the central office. At the end of the interview, he or she was asked to name other persons with extensive experience in the design and operation of two-lane rural roads. DOT personnel contacted were strategically selected to obtain representation from both the central and district (regional) offices, as well as the design, traffic, and safety departments.

Each interview was tape-recorded for note-taking purposes. Generally, respondents did not receive advance notice regarding the interview or the questions that would be asked. Each interview was based on a set of prescribed questions, but the responses frequently prompted spontaneous questions, as well. Respondents were asked to base their questions on professional opinion and knowledge of projects completed under their supervision. No examination of project files or State design standards was requested. The primary contact in each State was asked the following questions, to gain general information about improvement projects on two-lane rural roads:

- How do you identify safety problems on two-lane rural roads, and who is responsible for this task?
- How is available funding allocated to the districts? Who actually programs the projects?
- What are potential sources of documentation regarding safety improvements?

Each interviewee (including the primary contact) was asked:

- What are the most problematic situations on two-lane rural roads?
- What are the typical safety-related improvements that you make as part of a 3-R or safety-funded project?

- Has an evaluation of the number of accidents before and after construction been performed by the DOT?

Table 11. DOT personnel participating in telephone interviews.

State	Name	Department	Name	Department
Florida	Pat Brady Ed Rice Freddie Simmons Billy Hattaway John Grant	State Traffic Safety State Traffic Safety State Design State Design State Design	Robert Pearce Eugene Toole Brian Fregosi Glen Smithy	District Design District Design District Traffic District Plans
Michigan	Curt Kunde Dale Lightheiser Tom Myers Mark Bott	State Traffic Safety State Design State Design State Programming	Robert Briere Dan Lund Dwight Hornbech Wayne Gunderman Gary Carton	District Traffic District Traffic District Traffic District Design District Design
Minnesota	D. Bouzarjomehri David Ekern Gerry Rohrbach Jonette Kreideweis	State Traffic Safety State Design State Design State Planning	Mike Sheean Larry Filter Leonard Follman Mark Flygare	County Design District Design District Design District Traffic
New York	Bruce Smith John Bray Art Perkins	State Traffic Safety State Traffic Safety State Design	Ray Powers Dan Paddick Gary Funk Bob MacMonigle Chuck Debonar Bill Seaman	Region Traffic/Design Region Traffic/Design Region Traffic/Design Region Traffic/Design Region Design Region Traffic
Oregon	June Ross Terry Wheeler	State Traffic Safety State Design	Willard Bradshaw Kip Osborn Steve McNab Bob Bryant	Regional Traffic Regional Traffic Regional Traffic Regional Tech. Services
Pennsylvania	Thomas Bryer Jim Tenaglia Dean Sehreiber	State Traffic Safety State Traffic Safety State Design	Steve Maclean Tim Pieples Tom O'Hearn Ken Lippman Stan Poplawski	District Plans District Traffic District Traffic District Plans District Traffic
Wisconsin	Pete Rusch Bob Bovy Dick Lang Chuck Thiede Mike Schumaker	State Traffic Safety State Programming State Traffic State Programming State Traffic Safety	Roger Winter John Kuhl Leroy Messler	District Traffic District Design District Design

In-Person Interviews

Five DOT offices in Pennsylvania (PennDOT) and New York (NYSDOT) were visited over a period of 3 days to determine if additional knowledge could be extracted through in-person interviews. Interviews were held at PennDOT offices in Harrisburg and Allentown. NYSDOT offices in Albany, Binghamton, and Poughkeepsie also served as interview sites. In-person interviews were completed with 12 individuals. Table 12 lists the name and department of each person who participated. As Table 12 shows, the experience of most interviewees emphasized geometric design. DOT personnel who were previously contacted for a telephone interview were asked to arrange each meeting with others in their departments. They were asked not to schedule anyone who had taken part in the telephone interview. Three of the twelve interviewees, however, had participated, and were inadvertently scheduled.

Table 12. DOT personnel interviewed in person.

State	Name	Department	Name	Department
New York	Art Perkins Jim Dunham	State Design State Design	Rob Fitch Chuck Debonar Bill Seaman Chet Burch Bill Groton	Region Design Region Design Region Traffic Safety Region Design Region Design
Pennsylvania	Gary Fawver Daniel Stewart Daryl Kerns	State Design State Design State Design	Charlie Bauer Chris Lee	District Design District Design

Each interview was tape recorded for note-taking purposes and lasted approximately 30 to 45 minutes. In contrast to the telephone interviews, a one-page summary of the interview objective and questions that would be asked was sent to the interviewee several days in advance. Several engineers prepared written responses to the questions and brought the sheet to the interview as a reference. As in the telephone interviews, respondents were asked to base their answers on professional opinion and knowledge of projects completed under their supervision. No examination of project files or State design standards was requested. The topics discussed during the interview included:

- The person's title, duties, years in current position, and areas of expertise.
- A description of situations thought to be the "biggest" problems on two-lane rural roads.
- The design review process and reasons for design exceptions.
- Corrective actions for problematic combinations of design features.
- Archived data at the project and program levels.
- The use of CADD software and methods of data collection for plan development.
- The amount of design work performed by consultants versus DOT personnel.

HSIP Documentation

Projects completed with HSIP funding are documented in a standard reporting form submitted annually to the FHWA Office of Highway Safety. The standard reporting form is a one- to three-page spreadsheet that lists the type of improvement, cost, quantity, number of before-and-after accidents (over 3-year periods, respectively), before-and-after AADT, environment (rural or urban), number of lanes, and whether the roadway is divided or undivided. The FHWA classification system for HSIP projects completed on two-lane rural roads is shown in table 15. Depending on the State, the HSIP annual report submitted consisted of the standard reporting form accompanied by either a brief memo or a detailed report. The FHWA compiles data from the standard reporting forms and summarizes the findings in an annual HSIP report.(52) Each of the seven States' standard reporting forms (1996) were obtained through the FHWA Office of Highway Safety or the respective DOT's. Within a State DOT, the Office of Traffic Operations or the Office of Safety Programs Management is generally the section responsible for completing the HSIP standard reporting form.

Table 13. FHWA classification of HSIP projects completed on two-lane rural roads.

Code	Description	Code	Description
Intersection/Traffic Control Devices		**Roadway and Roadside Improvements**	
1A	Channelization and/or Turning Lanes	3A	Widened Traveled Way (No Lanes Added)
1B	Sight Distance Improvements	3B	Lanes Added to Traveled Way
1C	Traffic Signs	3D	Shoulder Widening or Improvements
1D	Pavement Markings and/or Delineators	3E	Roadway Realignment
1E	Illumination	3F	Skid-Resistant Overlays
1F	Upgraded Traffic Signals	3G	Skid Treatment by Grooving
1G	New Traffic Signals	3H	Breakaway Sign Supports
Structures		3I	Relocated or Breakaway Utility Poles
2A	Bridges Widened or Modified for Safety	3J	Guardrail End Treatments
2B	Bridge Replacements for Safety	3K	Upgraded Guardrail
2C	New Bridges Constructed for Safety	3O	Flattened Sideslopes
2D	Minor Structures Replaced or Improved for Safety	3Q	Upgraded Bridge Approach/Guardrail Transitions
2E	Upgraded Bridge Rail	3R	Obstacles Removal

Design Checklists

Since the DRC will be a design assistance tool, interviewees were asked if they used a checklist at any point in the design process. The checklist might include "things to look for" or "frequently overlooked elements of good highway design." Two checklists were obtained as a result of the telephone and in-person interviews. The checklists reviewed (source in parentheses) consisted of the following:

- Scoping checklist (Wisconsin), which is used when the project scope (extent and types of improvements) is determined.

- Design review checklist (New York), which is used after the plans have been generated. A review occurs to ensure that the design meets the original project objectives and has addressed all safety concerns.

RESULTS

Telephone Interviews

Responses to the telephone interviews are summarized here under each question. The responses are ranked by frequency and are followed by the number of repeat responses in parentheses. Please note that approximately 60 individuals were interviewed. This manner of reporting the results is intended to summarize the variety of responses and the relative frequency of similar answers to a given question. The questions were not asked in a multiple-choice or yes/no format; therefore, responses were grouped according to the subject of the answer. In general, interviewees provided answers to only a portion of all questions asked, because some were focused on geometric designers, while others were directed at traffic engineers. Many responses contained multiple answers. The final bulleted item in this section, "Selected Comments," summarizes other remarks relevant to implementing the DRC or the IHSDM.

How do you identify safety problems on two-lane rural roads, and who is responsible for this task?

- Accident rates on a section are compared with the statewide average. When the crash rate at an intersection or along a segment of State roadway exceeds a statistical threshold (number of standard deviations), then it is identified for review. It is an automated process performed at the central office. Districts receive data on the sites and have a standard procedure for evaluating the need for corrective actions. The actual site analysis is done entirely at the district level. Safety improvements are ranked for funding allocation according to some form of benefit-to-cost rating. The benefit-to-cost rating is supplemented by engineering judgment, knowledge of local operating conditions, and public input (5).

- District personnel must investigate the top 10 to 20 percent of the sites on the listing of high-accident locations (3).

- Information about sites may also come from maintenance, local government, district input, and public complaints (1).

How is available funding allocated to the districts? Who actually programs the projects?

- District engineers are responsible for programming, but central office personnel are usually involved (5).

- Initial allocation is based on each district's population and number of lane-miles. Ultimately, funding decisions are made on the basis of cost/benefit ratios. The expected number of crashes eliminated (stratified by severity) is compared to the project cost (2).

- The central office receives prioritized project lists, based on benefit/cost ratios, from each district and then develops the overall program (2).

- District engineers have short-range estimates of future funding levels and plan their projects accordingly (1).

What are potential sources of documentation regarding safety improvements?

- Archived sets of plans (6).
- The programming department can give annual summaries of project scope and cost (3).
- Individual project reports for safety, 3-R, and reconstruction projects (2).
- Standard reporting form in the HSIP (1).

What are the most problematic situations on two-lane rural roads?

- Narrow/no shoulders (9).
- Culverts, obstacles close to the edge of the roadway (8).
- Pavement edge drop-off, steep sideslopes (7).
- Narrow lanes (7).
- Lack of passing opportunities (7).
- Combinations of vertical and horizontal alignment (6).
- Lack of left-turn lanes (5).
- Density of access points or new access points (5).
- Intersections at the top of vertical curves (4).
- Horizontal curves (4).
- Insufficient length or location of guardrail (4).
- Isolated signalized intersections (3).
- Skewed intersections on horizontal curves (3).
- Lack of signing or delineation (3).
- Narrow bridges (2).
- Intersection sight-distance restrictions due to vegetation, topography, or structures (2).
- Lane drops over the crest of a vertical curve (2).
- Lack of proper superelevation (2).
- Long tangents without curvature, drivers falling asleep (2).
- Lack of intersection lighting (1).
- Reverse curves with the improper tangent length for the superelevation transition (1).
- Poor pavement condition (1).
- Lack of right-turn lanes or proper deceleration length (1).
- Inadequate drainage (1).

What are the typical safety-related improvements that you make as part of a 3-R or safety-funded project?

- Pave or widen shoulders (18).
- Add left-turn lanes (16).
- Improve guardrail (13).
- Flatten vertical or horizontal curves (13).
- Install signals (12).
- Add superelevation to curves (10).
- Add raised pavement markers/delineation/signing/rumble strips (9).
- Add passing/truck-climbing lanes (7).
- Remove or protect obstacles in clear zone (7).
- Add bypass lanes (6).
- Improve intersection sight distance (6).
- Widen bridge or travel lanes (5).
- Add continuous left-turn lanes (5).
- Skid hazard reduction (4).
- Flatten sideslopes (4).
- Add right-turn lanes (4).
- Flashing beacons at intersections (3).
- Driveway improvements, access management (2).
- Channelization at intersections (2).
- Add truck-climbing lanes (1).
- Increase corner radii (1).
- Pavement widening at intersections (1).
- Improve drainage (1).

Has an evaluation of the number of accidents before and after construction been performed by the DOT?

- See the HSIP standard reporting form (3).
- Central office would do this type of analysis (3).
- If the site does not reappear on the list of high-accident locations in subsequent years, then the treatment is deemed effective. Before/after studies are not generally done (2).

Selected Comments:

- Safety projects may be identified not just by crash rate but by the proportion of crashes of a similar type, or under similar conditions. Example types include wet weather, truck involved, pedestrian involved, and nighttime.

- Vertical or horizontal realignment is rarely done because of cost, needs for additional right of way, and time required from planning to construction (3).

- Designers generally have no involvement in the identification of hazardous locations.

- New construction of two-lane rural roads is negligible. Reconstruction or 3-R type projects must address design speeds that are much lower than the current operating speeds on the facility. Speed is a major factor in rural-road accidents (3).

- Design criteria are driven by the minimum standards. Resources do not generally permit a dedicated safety assessment. This is the responsibility of the safety (traffic) office.

- Safety improvements must be justified by an accident history that will be reduced or eliminated as a result of the project. This often precludes projects in rural areas, due to the low volumes and frequencies (or rates) of accidents.

- Safety projects with Federal funding must be constructed according to new construction criteria. Where this is not possible, the project may be constructed in the 3-R program, because criteria are generally lower than those for new construction.

- Representatives from design, construction, real estate, environmental, and traffic are involved in the project-scoping process to identify all potential concerns. Later, at the design review stage, the designer has intimate knowledge of the project scope, concerns, and budget. Design review is simply a fine tuning of the project plans (2).

- Sometimes, bringing the alignment up to current standards is not practical, but an improvement in that direction may be effective.

- For a safety evaluation of rural-road sections, checking with the county sheriff, county engineer, or local EMS is important, because many accidents may go unreported.

- The desired expenditure for a single safety-improvement project completed with Federal funds is less than $500,000. More expensive projects may be postponed until other sources of funding become available.

Office Visits

The information obtained from the office visits is reported in a format similar to the telephone interviews. Comments are followed by the number of repeat responses in parentheses, ranked by frequency. Please note that the results are based on interviews with 12 persons. This method of reporting the results is intended to summarize the variety of responses and the relative frequency of similar answers to a given question. The questions were not asked in a multiple choice or yes/no format; therefore, responses were grouped according to the subject of the answer. Many responses contained multiple answers. The final bulleted item in this section, "Selected Comments," summarizes other remarks relevant to implementing the DRC or the IHSDM.

What are the most problematic situations on two-lane rural roads?

- Intersections at sag or crest vertical curves (5).
- Combinations of vertical and horizontal curvature (4).
- Narrow shoulder width (3).

- Lack of proper superelevation (3).
- Horizontal curves following long tangents (3).
- Intersection sight distance (2).
- Intersections without reference points (e.g., trees, utility poles) on the main roadway (2).
- Lack of passing opportunities (1).
- Obstacles in the clear zone (1).
- Improper placement of guardrail (1).
- Drainage outside the right-of-way limits (1).
- Steep sideslopes (1).
- Horizontal curves to the left on downgrades (1).
- Lack of left-turn lanes (1).

What specific items, besides the design criteria, are you checking for in a design review?

- Proper implementation of safety and/or design report recommendations (3).
- The actual operating speed versus the design speed (2).
- The location and radii of driveways (2).
- Turning radii at intersections versus the design vehicle (1).
- Roadside objects that may restrict sight distance at intersections (1).
- Guardrail placement and guardrail end treatments (1).
- Culvert end treatments in the clear zone (1).
- Proper amount of right of way acquired (1).

What are the primary reasons for design exceptions?

- Insufficient accident history to warrant the cost of the improvement (3).
- Cost or environmental impacts of bringing a section up to current standards (3).
- Historic structures near the roadway (3).
- Commonly a shoulder-width exception due to a prohibitive cost of widening (2).
- Depends on the relative cross section and alignment of adjacent sections (1).

What are typical corrective actions for problematic combinations of design features?

- Increase intersection sight distance (5).
- Add superelevation (3).
- Remove obstacles from the clear zone (3).
- Flatten vertical or horizontal curves (3).
- Add left-turn lanes (3).
- Add signing, delineation, pavement markings (3).
- Widen lanes and shoulders (3).
- Guardrail improvements (2).

What data are available at the project and program levels?

- Best sources are the district offices (4).
- Plan and profile is kept in paper files; other sheets are microfilmed (3).

- For future projects, see the traffic and safety section (1).
- For active projects, see the design squad supervisor or liaison engineer (1).
- Photologs: pictures of the road every 15.2 m (50 ft) (1).

Describe the use of CADD software and methods of data collection used by the department.

- Photogrammetry, supplemented by field survey of pavement, is used to develop plans (3).
- More than 90 percent of the design work is on CADD (2).
- Old as-builts may be used to lay out the existing alignment (2).
- Data include turning-movement counts, percent trucks, LOS, and accident analysis (1).
- The lead CADD operator keeps an archive of electronic files (1).

The percentage of design work performed by consultants versus DOT personnel.

- 10 to 50 percent (4).

Selected Comments:

- The design standards present the desirable situations. There is limited guidance, however, on what to do when these situations cannot be met. This is generally the case for two-lane rural roads. Additional guidance may make it more difficult to make good decisions.

- Computer software must save time and resources. Additionally, it must produce a better design at the same or slightly higher cost.

- Projects are constructed in an effort to balance economic, environmental, political, and public issues. There is no substitute for engineering judgment in most cases.

HSIP Documentation

HSIP annual reports for fiscal year 1996 (July 1, 1995 to June 30, 1996) were obtained from seven States. The standard reporting form of evaluation data was examined to determine the types of projects completed on two-lane rural roads. Table 14 lists the total number of HSIP projects reported in each State, the number of rural projects, and the FHWA classification of improvement type.[52-56] Only nonrailroad grade-crossing projects with Federal-aid funding are listed in table 14. The FHWA funding category for these projects is either HE (hazard elimination) or FA (other improvement made with Federal-aid funds). The purpose of this reporting form is to list the number of accidents occurring before and after the improvement. The before-and-after periods vary from 12 to 36 months in length. Thus, projects listed in the 1996 report were actually constructed during fiscal years 1992-1994.

As shown in table 14, the complete data set from four of the seven States was insufficient to classify HSIP projects by rural or urban area and then further by project type. Florida and Oregon did not report any rural projects in FY 1996. New York and Wisconsin reported that rural projects consisted of approximately one-third of the total number. The majority of the rural projects in New York (9 of 14) were signage improvements. The majority of rural projects in Wisconsin (5 of 9) were roadway realignment projects.

Table 14. Summary of HSIP projects on two-lane rural roads reported in FY 1996.

State	Number of HSIP Projects Reported	Number of Rural Projects	Project Classification (Quantity)
Florida	18	0	N/A
Michigan	12	Not provided	Not provided
Minnesota	13	1	Not provided
New York	37	14	Traffic Signs (9) Roadway and Roadside Improvements (3) Roadway Realignment (1) Upgrade Traffic Signals (1)
Oregon	8	0	N/A
Pennsylvania	31	Not provided	Not provided
Wisconsin	32	9	Roadway Realignment (5) Sight Distance Improvements (2) Channelization and/or Turning Lanes (1) Traffic Signs (1)

In addition to containing the FHWA standard reporting form of evaluation data, the HSIP annual reports of some States also described activities related to the Safety Management System (SMS). A few such activities were:

- Minnesota has budgeted $6,000,000 for improvement of its accident data collection and storage capabilities. System features will include new statistical reporting capabilities, in-vehicle reporting and downloading, and GPS usage for locating crashes.[55]

- The Wisconsin HSIP report discusses the funding of improvements at sites with crash potential. However, the report states that the FHWA will not fund such locations unless a systematic analysis is completed to identify all situations statewide. This suggests the development of a Hazard Index; however, the department does not have sufficient resources to pursue such an effort at this time.[54]

- New York is developing an Expected Value Analysis (EVA) system for determining abnormal-collision type patterns at intersections. The computer program is designed to determine what collision patterns exceed the expected value. It will then generate the estimated safety benefit, in dollars, that would result from reducing the number of crashes to equal the expected number.[56]

Design Checklists

Interviews with DOT personnel provided valuable insight regarding the stages of project development and the involvement of designers at each stage. In general, these four stages are: (1) initiation (sometimes called concept definition), (2) scoping, (3) design, and (4) construction. In the initiation stage, the project is proposed in a brief report (sometimes no more than one page) that describes the location and types of improvements planned, and includes a preliminary cost estimate. If the report is approved, the scoping process begins. In the scoping stage, most of the design decisions are made. Many of those interviewed in this study indicated that the scoping process has changed over the last several years. A "scoping team" is now assembled, which may include representatives from design, real estate, utilities, maintenance, traffic, structures, planning, environmental, materials, and construction. Each member receives the concept definition report and any other pertinent information. Scoping checklists are given to each member to provide assistance in reviewing those aspects of the projects falling under their jurisdiction. The members then meet to prepare a memorandum of understanding, which further specifies the scope of the project, as agreed upon by the team.

The scoping checklist used by designers in the Wisconsin DOT contains the basic set of features to be compared with the appropriate design standards. These features include the following:

- Design speed.
- Degrees of curvature.
- Percent grade.
- Stopping sight distance.
- Intersection angles (less than 75°) and adequate geometrics, based on design year ADT.
- Lane width, shoulder width, cross slope, and superelevation.
- Provisions for passing or hill-climbing lanes.

The Wisconsin DOT's memorandum of understanding signed at a scoping meeting includes the following items related to the geometric design:

- Project length and termini.
- Proposed improvement type and design class.
- Design speed.
- Horizontal/vertical alignment and cross section.
- Clear-zone improvements and guardrail requirements.
- Intersection realignments and upgrades.
- Bypass lanes and turn lanes needed.
- Acquisition of right of way.

Once the scope of a project has been decided, the design process begins. A checklist obtained from the NYSDOT Design Quality Assistance Bureau highlights frequently overlooked elements of good highway design. These items include the following:

- Snow storage areas.
- Roadway widening at sharp curves.

- Point at which a horizontal curve begins just beyond the crest of a vertical curve.
- Effect of grades on the lengths of acceleration and deceleration lanes.
- Lack of spiralization.
- Short tangents between curves.
- Appropriate turning radii for design vehicle.

Summary

The investigation into seven States' HSIP produced the following key points:

- The DOT central office is responsible for the collection of accident data and the identification of high-accident locations. Data are made available to the district offices, which are responsible for site investigation and development of countermeasures. Sites may also be identified through input from local jurisdictions.

- Sources of project-level information include the archived plans, corresponding design reports, and the HSIP annual report. The plans provide before-and-after geometric information. The design reports contain all related documentation and may indicate the reasons for specific improvements and design exceptions (locations that were not brought up to current standards). The HSIP reports contain before-and-after accident data for projects classified according to the codes in table 13. The individual projects, however, are not described in sufficient detail to allow further analysis.

- Safety improvements are accident-driven if the benefit-to-cost ratio exceeds 1.0. Where the ratio is less than 1.0, design exceptions are often made, or the project fails to receive funding.

- The problematic situations most frequently identified by DOT engineers include: narrow lanes and shoulders, obstacles within the clear zone, steep sideslopes, insufficient passing opportunities, combinations of vertical and horizontal alignment, intersections on crest vertical curves, and improper superelevation. Improvements most frequently identified include: shoulder widening, new left-turn lanes, flattening of curves, new or improved signals, superelevation improvements, and signing/delineation.

- Before-and-after accident studies are rarely done by State DOTs, due to the number of years required in the "after" period. If the site receiving the improvement does not reappear as a high-accident location, the treatment is deemed effective.

- In the project scoping phase, the design decisions are made by representatives from several areas, including traffic, design, and maintenance, among others. These decisions may be made before a CADD-generated drawing is prepared. The designer assigned to review the plans is usually the person who has been involved since the project scoping. This process is merely fine tuning, since the major concerns have already been addressed, and the designer is intimately familiar with the site and related concerns from previous involvement.

- Design checklists offer guidance on "what to look for" and may suggest additional emphasis areas. Most checklists simply outline a procedure for systematically checking each existing design feature versus the criteria; a specification in geometric design units of measure is not provided.

ADVANTAGES, DISADVANTAGES, AND REQUIRED LEVEL OF EFFORT

The telephone and in-person interviews provided valuable data for a first pass at the DRC knowledge base, and limited data were gained from the HSIP reports and checklists. Many potential emphasis areas were identified by State and district DOT personnel. The frequency of repeated answers suggested that certain emphasis areas warrant further specification for inclusion in the DRC. This effort also provided a significant amount of insight into the design process. It is important to understand this process from a user's perspective in order to plan the eventual implementation of the IHSDM and its desired features. The HSIP annual reports have limited value because they do not provide specific information on the actual improvement(s). An adequate description, for example, would be, "Lanes widened from 2.7 to 3.3 meters," or "Curve radius lengthened from 100 to 200 meters." A high level of effort would be required to obtain information about each HSIP project to a necessary level of detail. The checklists reviewed could be used to develop the DRC's interactive checklist feature, but they have little application for the automated review. The checklists did indicate the fact that many personnel outside the design division make comments influencing the eventual design. In addition, the checklists identified a few potential emphasis areas that were not mentioned in the interviews.

Interviews

The telephone interview method enabled the collection of responses from approximately 60 persons in less than two months. Thus, an enormous amount of data was collected in a short time. This method was appropriate for the first pass at the knowledge base, because it was limited to generating a set of potential emphasis areas. Despite this success, this method has several disadvantages. Participants did not receive advance notice of the interview topic or questions; they were therefore asked to think "off the top of their heads." Better results may have been obtained if the respondents had received the questions in advance. Additionally, the participants did not generally have a clear concept of the IHSDM or the ultimate objective of the interview. Also, most of the personnel interviewed were not competent in CADD software. The uncertainty of the interview objective may have left some respondents less motivated to offer detailed responses. Finally, much of the data was repetitive; after approximately 20 of the 60 interviews were completed, the remaining interviews offered little added information.

For the in-person interviews, a summary of the IHSDM concept and the questions to be asked were faxed to the participants several days before the interview. When the interview began, each person had a basic idea about the objective of the conversation. Some had prepared written responses to the questions. Since an interviewer had traveled to meet with them personally, the interest level of the DOT personnel increased, resulting in higher quality responses. Most of the information provided, however, could be obtained over the telephone. For the first pass at the knowledge base, this was not deemed a cost-effective method of extracting information. The in-person interviews, however, did reveal the benefits of obtaining a mutual understanding about the IHSDM and the interview objectives before the conversation.

Project-Level Documentation

The HSIP reporting form distinguishes two-lane, rural-road projects from safety improvements constructed on other facilities, however, no further quantitative description of the improvement exists. To obtain such information would require a person in the DOT central office to identify the project (job) numbers for each project type listed on the form. The next step would be to contact the respective districts for copies of the project plans and corresponding documentation. This process requires a significant level of effort, with limited results. The HSIP report, however, appears to be the only source of before-and-after accident data for individual projects. DOT personnel indicated that other before-and-after studies are not generally done, due to the time requirements of the "after" period. Finally, the classification of HSIP projects into one category may not indicate other types of work completed as part of the project. For example, a project classified as "shoulder widening" may also include guardrail improvements and minor realignment.

The only source of data that provides sufficient project-level details is the project plans accompanied by the design report. The design report may provide insight as to the factors affecting the decision either to modify a feature, or to generate a design exception. The best source of project-level data is the district or regional DOT offices. The central office may have copies of the plans, but will generally not have the corresponding design report. Archived files at DOT offices are public property and copies can be obtained for a fee. Generally, a segment of the design department is responsible for the archiving of plans and design reports after projects are completed.

Required Level of Effort

In subsequent passes at the DRC knowledge base, little knowledge could be obtained through additional unstructured interviews. This effort, however, was an effective means of generating data for the first pass. To expand on the problem emphasis areas developed in this effort, structured interviews are recommended. In a structured interview, the expert is asked a series of questions about a specific situation, with the expert's answers resulting in preliminary elements of the knowledge base. The questions would be posed with the objective of developing either items for the interactive checklist, or numerical design guidelines for the automated review. Another form of a structured interview would have the expert review the current structure or content of the knowledge base.

While knowledge of completed projects is the cornerstone of an expert's wisdom, an analysis of individual projects alone is not likely to be beneficial. Archived plans and individual design reports are believed to be the only source of documentation that provides data in a format translatable for the automated review. It is not likely that a review of archived plans and design reports will be a cost-effective approach leading to additional findings. An examination of highway improvement projects in the planning or preliminary design stages may help identify locations for site investigations. Thus, the method could be used as a preliminary step to conducting multidisciplinary site investigations.

IMPLICATIONS FOR DEVELOPING THE DRC KNOWLEDGE BASE

Interviewing Techniques

This effort has provided valuable insight into a recommended interviewing technique for subsequent work. Future interviews to develop the DRC knowledge base should:

- Generally be conducted via fax or telephone. The added cost and time associated with in-person interviews does not justify further efforts in this area. Interviews should be conducted in person if a group discussion or consensus is deemed necessary, or if a prototype is ready for evaluation.

- Clearly establish the concept of IHSDM and the DRC in advance. The respondents should have an appreciation for why they have been selected to participate and the benefits of the resulting product. This will motivate them to assist the research team in the difficult process of knowledge acquisition.

- Clearly establish the objective of the interview in advance. Future interviews may be conducted in an effort to generate problem-area specifications. The interviewee should fully understand in advance the expectations to provide such specifications in geometric design units of measure.

Designers and Traffic Engineers Roles

This research effort indicated that designers and traffic engineers within State agencies should be included in the pool of experts. The persons with the most intimate knowledge of individual projects are generally found at the district or regional offices. They are likely to be the individuals most knowledgeable of potential problems and the range of viable corrective actions, based on their recollection of specific locations in their jurisdiction. Additionally, they may be most qualified to describe a potential problem in geometric design units of measure. Generally, the central office personnel become involved only in an advisory or auditing role, to ensure that the project addresses all appropriate concerns. Many central office personnel, however, originally held positions at the district level. Depending on their number of years away from a district position, they may still be able to provide information based on knowledge of individual projects.

An important issue surfaced through the discussions with State and local engineers. Currently, the most experienced designers and traffic engineers are not generally competent in CADD software. They are responsible for making design decisions, generating sketches, and making changes on paper plans, but they do not actually edit the drawing using the computer. Due to the salaries that persons in these positions command, it is not generally cost-effective to train them to use the software. Editing is the responsibility of draftspersons. Conversely, personnel in the drafting section are not generally familiar with the principles (or rules of thumb) that provide the basis for a design. This situation is changing, however, since many engineers with less than 10 years of experience have received training in CADD software. These engineers may rely on the assistance of draftspersons, but they are also skilled enough to do the drafting themselves, if necessary. Thus, the user population of the IHSDM is likely to consist of an increasing number of traffic engineers and designers, but currently a significant number of potential users are skilled in drafting alone.

State and Local DOT Personnel Perspectives

Throughout the course of nearly 70 interviews, comments were made about IHSDM features needed for successful implementation. While such remarks may not have direct implications for the DRC knowledge base, they should be considered by the FHWA as the structure and content of modules in IHSDM continue to evolve. These comments are summarized as follows:

- Implementation of the IHSDM could affect a State's project development process. Most of the design decisions are made before the plans are generated with CADD software. The use of IHSDM may require the collection of field data (by photogrammetry or topographic survey) and preliminary design work before the scoping process begins. It is difficult to make adjustments once the scoping process has been completed.

- Many States have undergone downsizing in recent years and have shifted much of their design work to private consultants. The perspectives and needs of private consultants should be considered in the development of the IHSDM. Thus, in an environment of limited resources, IHSDM may result in a better design at the same or slightly higher cost of generating the plans.

- The desirable (standard) design on a two-lane rural road is often not one that can feasibly be constructed. Topography, structure proximity, limited right of way, and environmental issues often restrict such work. The IHSDM recommendations should include potential low-cost improvements, such as signage or delineation.

- Safety improvements are rarely made unless they are justified by a crash history. Benefit/cost ratios often provide a formula to determine what improvements receive funding over others. The incorporation of crash data into an IHSDM module would be beneficial. One of the first questions posed by users will be, "How much will the improvement cost and what is the value of benefits resulting from crash reduction?" IHSDM should be able to perform the analysis to answer this question.

- The IHSDM must allow the user to modify the design specifications to suit specific needs. Design specifications may vary according to climate, topography, driving population, and design vehicle. Additionally, 3-R standards are different for each State.

SUMMARY

This chapter described an investigation of the potential benefits of using information from States' Highway Safety Improvement Programs (HSIP) to construct the DRC knowledge base. The scope of this effort was not limited to reviewing documentation of HSIP projects, because preliminary efforts revealed that most safety-related improvements on two-lane rural roads are funded outside the HSIP. Focusing on seven States, the study consisted of telephone and in-person interviews with approximately 75 State agency personnel, a review of checklists used by State design sections, and a review of each State's 1996 HSIP annual report submitted to the FHWA.

The interview format was unstructured; interviewees were asked open-ended questions regarding the most problematic situations on two-lane rural roads, typical safety-related improvements, and potential sources of documentation on such improvements. Selected comments regarding the design process are summarized to elaborate further on the State agency perspective.

The knowledge of local traffic engineers and designers could prove useful and should be obtained through structured telephone interviews. The need to provide the interviewee with advance notice of the interview topic and an adequate explanation of the interview objective was emphasized. The HSIP annual reports contain before-and-after accident data, a distinction between urban and rural projects, and a general classification of the improvement type. The HSIP annual reports do not generally provide valuable information, but HSIP projects currently in the planning or design stages could be identified for field investigations.

The design checklists reviewed offered little of value for developing the automated review, but could be used for the interactive checklist. To conclude chapter 8, State agencies comments with implications for IHSDM were summarized into five major points.

CHAPTER 9. SYNTHESIS OF PROBLEM LOCATIONS AND APPLICATION TO THE DRC

Although the objective of this research project was neither to develop an expert system nor to complete the first pass for the DRC knowledge base, insights with respect to safety-deficient design situations were gained from experts, State highway agency personnel, site investigations, and a review of the literature. This chapter attempts to synthesize the situations most frequently identified by the knowledge sources investigated in this study. In addition, chapter 9 contains a discussion of the need for and the challenges of specifying these problem situations such that the knowledge base can be developed.

This chapter also provides an overview of the recommended processes to develop a first-pass knowledge base for the interactive checklist and automated review functions. Several alternative knowledge acquisition processes are also identified.

The results of this feasibility investigation revealed that one of the keys to the successful development of an expert system is the effective use of experts. Accident research and safety audit literature can and should be used to complement knowledge gained from other knowledge acquisition methods, most notably in the first pass. Data and before-and-after results from Highway Safety Improvement Programs (HSIP) can also supplement the knowledge acquisition process, including the identification of sites for field investigations. Thus, the recommended and alternative approaches employ some form of interviews with experts, along with literature and HSIP data providing supplementary information. To conclude chapter 9, alternative knowledge acquisition methods based on traditional expert systems development processes and current research are discussed.

DESIGN SITUATIONS AND GEOMETRIC ELEMENT COMBINATIONS

Constructing a knowledge base that encompasses all design considerations on two-lane roads is a formidable, if not impossible, task. The results of this research have identified a set of problem emphasis areas, or an arrangement of design considerations into workable components of the knowledge base. Subsequent efforts should focus on these selected problems, to maintain a manageable scope of work.

Table 15 summarizes potential problem emphasis areas, based on interviews of experts, investigations of selected high-accident sites, a review of safety-audit and highway safety research literature, and an investigation of selected State Highway Safety Improvement Programs. The situations are not listed in any prioritized manner, but an attempt is made to categorize the potential problem emphasis areas according to the applicable highway geometric design feature. It should be understood that this list is not meant to be comprehensive. However, it does contain many situations that were frequently identified by multiple sources as experiencing crash problems. In addition, table 15 lists the design elements that further describe each emphasis area.

The last column in table 15 presents the IHSDM module(s) applicable to each problem. Previously in this report, the potential for overlap between IHSDM modules was noted. For many problems listed in table 15, the most appropriate module may not be the DRC. For others, the problem could be addressed within the DRC, or possibly another IHSDM module. The FHWA should ensure careful coordination among all modules to avoid potentially overlapping research efforts. Where necessary, the FHWA should determine the appropriate module for each problem.

Table 15. Potential problem emphasis areas for IHSDM.

Primary Design Feature	Potential Problem Emphasis Area	Required Design Elements	Potentially Applicable IHSDM Module
Sight Distance (stopping, passing, intersection)	Lack of passing opportunities.	Horizontal and vertical alignment, intersection location, passing sight distance.	The Driver/Vehicle Module may flag these types of situations. The Traffic Analysis Module could also be used to identify potential deficiencies related to passing.
	Intersections with restricted inter-section sight distance (ISD).	Horizontal and vertical alignment, intersection design, roadside design, obstructions outside the right of way, intersection sight distance.	An IHSDM 3-D sight distance model could also be developed and applied. As there are policies for ISD, this situation could be covered by the PRM.
Alignment	Sharp horizontal curves preceded by tangent down-grades.	Degree of curvature, central angle, curve length, superelevation, percent downgrade, downgrade length.	DRC or the Design Consistency Module (based on the design speeds of curve and tangent sections).
	Winding road sections with sharp interior curves.	Horizontal alignment.	DRC or theDesign Consistency Module
	Isolated, sharp horizontal curves preceded by long tangents on level terrain.	Degree of curvature, deflection angle, curve length.	DRC or the Design Consistency Module
	Sharp vertical curves.	Starting and ending grades, K value, curve length.	DRC or the Design Consistency Module
	Horizontal curves without spiral transitions.	Horizontal alignment, cross section.	DRC*
	Horizontal curves beyond crest vertical curves.	Cross section, vertical curve information.	DRC

Table 15. Potential problem emphasis areas for IHSDM (continued).

Primary Design Feature	Potential Problem Emphasis Area	Required Design Elements	Potentially Applicable IHSDM Module
Alignment (continued)	Horizontal curves with improper superelevation.	Cross section, horizontal curvature.	DRC*
	Very long tangents.	Length of tangent.	DRC
	Reverse curves without proper transitions of superelevation.	Horizontal curvature, tangent length.	DRC*
Cross Section	Narrow or no shoulders.	Cross section, pavement marking.	DRC or the Policy Review Module
	Narrow bridges.	Cross section, pavement marking.	DRC or the Policy Review Module
	Narrow lanes.	Cross section, pavement marking.	DRC or the Policy Review Module
	Sudden transitions in cross section.	Cross section.	DRC or the Policy Review Module
Roadside	Culverts and fixed objects close to edge of the roadway.	Alignment, topographic data, and obstacles located beyond edge of pavement.	DRC
	Steep side slopes.	Alignment, topographic data, and obstacles located beyond edge of pavement.	DRC
	Improper locations or lengths of guardrail.	Alignment, topographic data, and obstacles located beyond edge of pavement.	DRC
Intersections and Driveways	Lack of left-turn lanes.	Traffic data,** cross-section, alignment.	DRC* or the Policy Review Module
	Improperly designed bypass lanes.	Traffic data,** pavement marking.	DRC
	Lack of right-turn lanes.	Traffic data,** pavement marking.	DRC*
	Lack of channelization.	Traffic data,** pavement marking.	DRC

Table 15. Potential problem emphasis areas for IHSDM (continued).

Primary Design Feature	Potential Problem Emphasis Area	Required Design Elements	Potentially Applicable IHSDM Module
Intersections and Driveways (continued)	Insufficient corner radii.	Traffic data,** cross section.	DRC or the Policy Review Module
	Inadequate lengths and/or tapers for turn lanes.	Horizontal alignment, traffic data,** pavement marking.	DRC* or the Policy Review Module
	Driveways in close proximity to intersections.	Location of driveways and intersections.	DRC
	Severely skewed intersections.	Horizontal and vertical alignment, intersection angle.	DRC
	Intersections at vertical curves.	Intersection sight distance, vertical alignment, location of intersection.	DRC
	High-speed approaches to isolated signalized intersections.	Traffic control devices at intersections, distance to nearest signal.	DRC
Other	Inadequate signing, delineation.	Location and type of all signs, pavement markings.	Not within the scope of any modules as currently conceived; may require an expert system that would assess the adequacy of a proposed sign and marking plan.
	Lack of lighting.	Information on lighting, presence of intersections and driveways, approach alignment.	Not within the scope of any modules as currently conceived; may require an expert system that would assess the adequacy of a lighting plan.

* The knowledge acquisition process may focus on identifying locations where the design meets AASHTO minimum standards, but a safety problem exists.

** Traffic data include: ADT (design year), turning-movement volumes (design year) at all intersections, and percent trucks, among others.

INTERACTIVE CHECKLIST DEVELOPMENT

A series of interactive checklists can be developed to address the problems listed in table 15. The interactive checklist should prompt the designer to consider a set of issues that may have been overlooked. Since there is no need to develop purely quantitative rules, knowledge acquisition focuses on the following three items:

- **Contents of checklist items.** The expert system development team must decide how to address each situation in the checklist, how to phrase checklist items, and what the nature will be of any recommended courses of action.

- **Intelligence level of the interactive checklist.** To gain the respect of the user, the checklist should not be a generic set of questions that appear each time the program is run. Specific checklist subgroups could be either prompted by the user (e.g., intersection-related) or automatically initiated by the program if it could identify the existence of specific features in the design plan (e.g., intersections, turn bays, etc.). In the first case, the system does not necessarily have to operate within CADD, while in the second case, the system must operate within CADD. In addition, in the second case, where more than one feature exists within the project limits (e.g., multiple intersecting roadways), the developers should decide whether the same checklist item is initiated for each feature or just once over the project limits.

- **Specification level of the checklist and recommended courses of action.** Again, the checklist must assume some order of intelligence, if it is to operate as an expert system. The checklist must prompt the user to "think like an expert" by pointing out issues that could be overlooked, or should allow the user to "query an expert" about possible corrective actions. Help screens similar to those envisioned for the automated review could be displayed to assist the user. The result should be an assistance tool that is neither too prescriptive nor so general that it fails to provide useful information. This issue was discussed in chapter 2.

The objective of knowledge acquisition is to develop the content, format, and intelligence level of the interactive checklist. As opposed to the automated review, specific geometric thresholds do not need to be created. However, a decision-tree logic that employs specific data elements will need to be developed. Consequently, the user will need to enter data in response to specific prompts from the program.

Consider the example of an intersection design. The first prompt might ask the user to enter data for the station number of the intersection, to extract data from the CADD file. Another prompt might ask for geometric data for those elements that cannot be imported from the CADD file. The program may then prompt the user for design-year traffic data, such as ADT volumes for each leg, a.m. and p.m. peak-period flows, design hour volumes, turning movements, and average approach speed. One component of the interactive checklist could then compare the combination of approach volumes and opposing volumes with guidelines for determining the length of a left-turn lane, including methodologies commonly used by State and local highway agencies. If the program determines that the length of the left-turn lane does not meet the guidelines, based on the traffic volume data, then a message could be issued, "Have you considered lengthening the left-turn lane?" If the answer is no, then the program could issue the message, "Projected volume conditions indicate that the length of the left-turn lane may need to be increased. Do you want to revise the design to incorporate a longer left-turn lane?"

Systematic Process to Develop the Interactive Checklist Knowledge Base

A schematic of the proposed approach for developing the DRC interactive checklist is shown in Figure 17. The recommended systematic process consists of the following steps:

Step 1. *Select the Situation of Interest.* As opposed to the automated review tool, there is no need to develop detailed specifications of safety-deficient design situations to create an interactive checklist. Consequently, problem emphasis areas do not need to be explicitly defined. Thus, rather than starting with a detailed definition of the problem emphasis area, such as "a sharp curve preceded by a long tangent downgrade," the process should start with a broadly defined situation. For example, a broadly defined situation is "an intersection." Based on this research, it is proposed that the first interactive checklist developed cover intersections of two-lane rural roads.

Step 2. *Define Relevant Design Attributes.* For this step, the design attributes applicable to the situation of interest would be identified. For example, intersection attributes would include the following elements, among others:

- Number of legs.
- Intersection geometry.
- Channelization.
- Intersection sight distance.
- Auxiliary lanes (e.g., left-turn, right-turn, bypass, and speed-change lanes).
- Corner radii.
- Median openings.
- Islands.
- Approach end-treatments to islands.
- Turning roadways.
- Vertical profile of intersecting roads.
- Horizontal alignment of intersecting roads.
- Accessible curb cuts.
- Pedestrian crossings.

Development of a comprehensive list will ensure that in subsequent steps, proper consideration is given to all elements that could contribute to a safety-related geometric design deficiency.

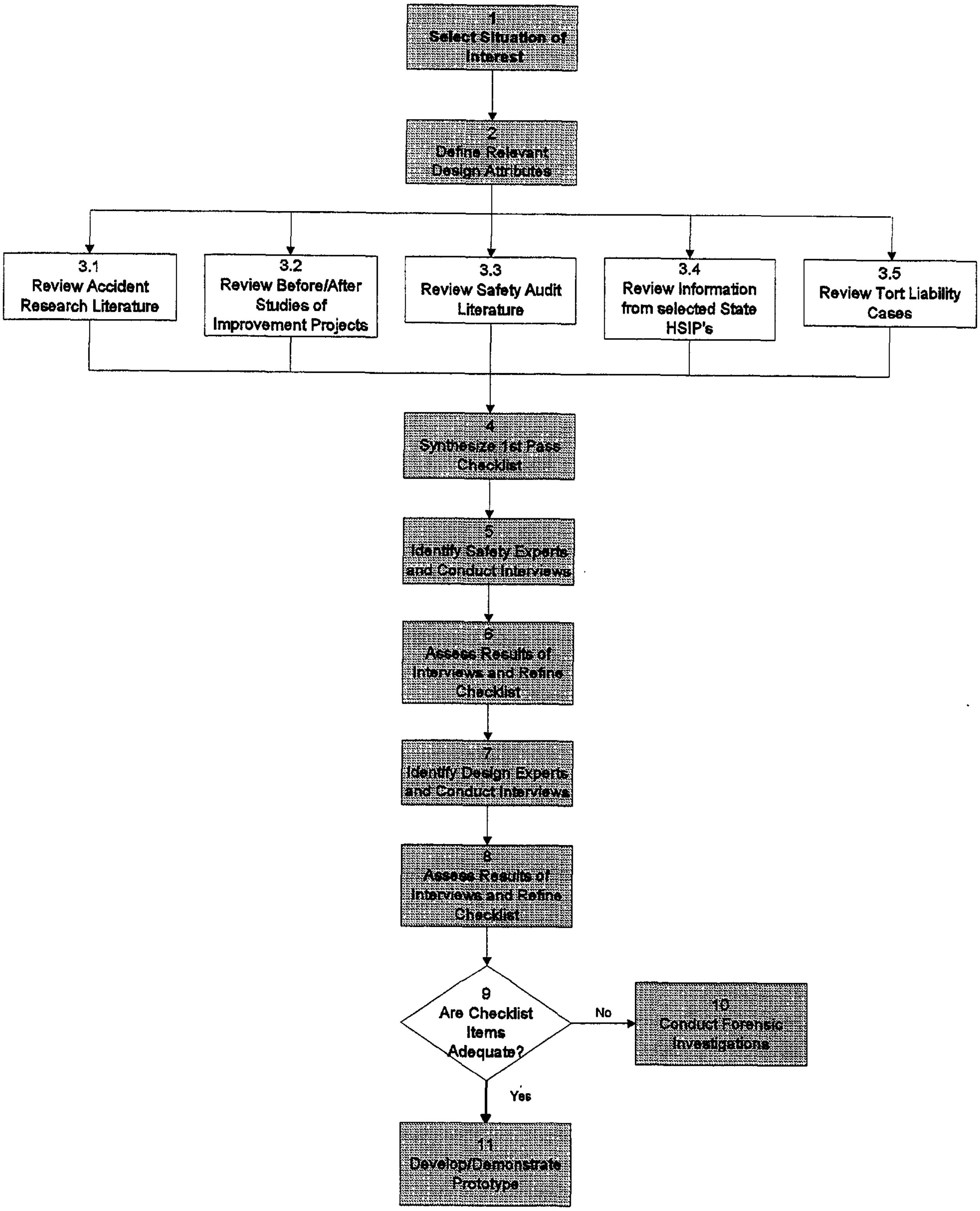


Figure 17. Proposed knowledge acquisition process for the interactive checklist.

Step 3.1. *Review Relevant Accident Research Literature.* It was shown in this report that for the automated review tool, detailed geometric specifications for safety-deficient design situations cannot be extracted directly from accident research literature. However, relevant findings from highway safety research can be used to develop the interactive checklist. Accident research and highway safety research literature relevant to the situation of interest should be reviewed and a synthesis of key findings produced. The emphasis should not be on accident statistics, but on the implications with respect to the interactive checklist. For example, statistics about the relative differences in accident rates between four-legged intersections and three-legged intersections do not provide useful information for the interactive checklist. However, findings from a study of high-speed approaches to isolated intersections may serve as a good reference for developing questions about this design situation.

Step 3.2. *Review Safety Audit Literature.* Similar to accident research literature, safety audit literature is not a promising knowledge source for the automated review tool but can be used to develop the interactive checklist. In fact, safety audit literature may be one of the most valuable knowledge sources for the development of the interactive checklist. However, it should be recognized that many items on safety audit checklists created by New Zealand, Australia, and Great Britain are fairly general, e.g., are the lane widths and swept paths adequate for all vehicles? Moreover, no additional guidelines related to suggested corrective actions are presented in those checklists.

Step 3.3. *Review State Highway Improvement Project Data.* For the situation of interest, the objective of this step is to obtain information about the design-related characteristics of the locations where improvement projects were implemented in selected States. Knowledge about the "before" problems can facilitate the development of an interactive checklist such that these problems are not repeated. In addition, information about the safety effects of those improvements, if available, should be gathered. As discussed in chapter 8, a review of Highway Safety Improvement Programs (HSIPs) should include projects outside just those that fall under the HSIP funding category. Significant knowledge also resides in State and local highway-agency personnel. Relevant information can also be gained from investigating other highway improvement projects, including rehabilitation and reconstruction projects implemented at the State level. Consequently, this step was expanded to include more than just HSIP data.

Step 3.4. *Review Before/After Highway Improvement Studies.* Although there may be some overlap with respect to this step and steps 3.1 and 3.3, reviewing before-and-after highway improvement studies is important because they may contain valuable information about the effectiveness of improvements. This will facilitate the identification of suggested corrective actions and help screens.

Step 3.5. *Review Tort Liability Literature.* A review of tort liability literature may shed additional insights into specific types of design-related accident problems that have not been identified by other methods. This may lead to the development of specific items on the interactive checklist, even if they are only applicable to a limited number of designs.

Step 4. *Synthesize the First-Pass Interactive Checklist.* After the successful completion of steps 1 through 3.5, the expert system development team should synthesize the findings into the first-pass interactive checklist. The expert system development team, left to their own devices, could conceivably develop a reasonable first-pass interactive checklist. Four alternative approaches could be used to assist in that development:

Method A. *An Approach Based on Underlying Principles of "Good" Design.* Mason indicated that the following two fundamental safety principles are paramount in the geometric design process:

- Provide adequate "lines of sight" for the operator of a vehicle to stop/maneuver in a reasonable manner.

- Ensure the concomitant alignments/cross sections do not exceed "design" acceleration/deceleration driver comfort control levels.[11]

Based on these two principles, a series of questions for the interactive checklist can be developed, which can be translated into logic that employs decision trees and then into rules for the expert system. For example, consider the first principle. Consideration of this basic principle for intersections would lead to the identification of the following types of questions:

- When attempting to cross the intersection from the side-road approaches, do drivers have sufficient sight distance to the left and the right? When attempting to turn right from the side road, do drivers have sufficient sight distance to the left? When attempting to turn left from the side road, do drivers have sufficient sight distance to the left and the right?

- When attempting to turn left from the major road, do drivers have sufficient sight distance to detect and react to a safe gap in opposing traffic?

- Can drivers on the major approaches detect the presence of the intersection from a sufficient distance to be able to respond properly?

- Are there any local features that will affect visibility?

- Are sight lines obstructed by embankments, fences, trees, bushes, other foliage, signs, bridge abutments, guardrails, signal poles, or other roadside hardware? Will sight lines become blocked after the project is completed?

- Will sight lines be obstructed by temporary features, such as parked or stopped vehicles?

- Will sight distance to traffic control devices be adequate?

After these questions are developed, the next effort would be to convert them into the logic and then the rules for the expert system. For each item to be included in the expert system, a data requirements analysis will be needed. For example, what are the data sources? Which data elements can and should be extracted from the CADD file? Which data elements should be input by the user? What is the reliability of the data? What types of automated checks should be included? What underlying quantitatively-based rules should be included, if any?

With a focus on these two principles, it is conceivable that a comprehensive, interactive checklist expert system can be developed.

Method B. *An Approach Based on Contributory Factors of Crashes.* As one of the State personnel interviewed for this study expressed, highway engineers should strive to create a "forgiving" design. It must be recognized that driver errors will continue to be made and crashes will result. Consequently, it is suggested that one approach would be to categorize the factors that contribute to crashes. This would include an enumeration of factors related to the driver, the vehicle, the highway, and the environment. For the driver, inappropriate driving behaviors can be identified. For the vehicle, vehicle-related factors exacerbated by roadway conditions can be identified. Environmental conditions, such as weather and visibility, and contributing highway-related factors can also be systematically identified. For each factor, its relationship to the design should be considered, which in turn will result in a series of items for the interactive checklist.

Method C. *An Approach Based on Possible Driver Actions.* A third systematic approach would be to employ Information-Decision-Action (IDA) human factors models. IDA models have been developed to identify driver information needs on two-lane rural roads. To develop the models, driver actions that are possible when a driver traverses the situation of interest need to be identified. For example, at an intersection, a driver may: (1) proceed through on the major road without having to yield, (2) turn left from a stop-controlled side road, or (3) respond to a yellow signal indication on the approach to a signalized intersection. After identifying the possible actions, the driver decisions would be enumerated. For each decision, the driver requires and/or utilizes specific information. Hence, IDA models are constructed.

A first-pass knowledge base for an interactive checklist can be created by employing a similar approach. By identifying all possible actions performed as a driver negotiates the situation of interest, the influences of crucial aspects of the design can be systematically identified. The design aspect can influence the action, the decisions made by the driver to execute the actions, or the information used by the driver to make the decisions. An example of how this approach could be applied to intersections would be as follows. A driver wants to turn left onto a side road. The driver must decide where to turn, at what speed to turn, when to decelerate, when turning is safe, etc. By considering each decision, the development team can consider how the design influences the decisions and can develop appropriate items for the interactive checklist.

Method D. *An Approach Based on Individual Design Elements.* The fourth alternative approach would allow the development team to consider each design element individually and then in combination, to develop rules for the expert system. In this way, all design-related aspects of the situation of interest can be systematically considered in the development of the interactive checklist.

Step 5. *Identify and Interview Safety Experts.* In this context, safety experts include human factors specialists, accident reconstructionists, expert witnesses for accident cases, highway safety researchers, and traffic engineers who are or recently have been involved with improvement projects encompassing the situation of interest. The objective is to have the first-pass interactive checklist reviewed by a select group of safety experts with applicable expertise. They can offer suggestions and criticisms of the preliminary version of the interactive checklist. For example, they may indicate that the interactive checklist has omitted a particular aspect of the design that has been found to have an influence on crashes. The knowledge engineer should determine if the interviews are to be conducted individually or in a group setting.

Step 6. *Assess the Results of the Interview and Refine the Interactive Checklist.* After the interviews, the development team should collectively consider the comments and criticisms of the safety experts and revise the interactive checklist accordingly.

Step 7. *Identify and Interview Design Experts.* As opposed to step 5, which involved experts who have knowledge about the relationship of crashes to highway geometrics, this step features the interview of experts who have knowledge about geometric design and design review. These experts would include senior designers who have demonstrated experience in the preparation and review of highway design projects related to the situation of interest. These senior designers should include those employed at State highway agencies, consulting firms, local (i.e., county) highway agencies, and the Federal Highway Administration, notably those involved with the Federal Lands Highway Program design group. Feedback on the current state of the interactive checklist expert system should be solicited from these designers, who are also potential users of the end product. In addition, it is highly desirable for these experts to describe and discuss how they currently review design plans related to the situation of interest, e.g., what items do they look for, how and when do they make judgments as to the acceptability of the design, and what is the underlying rationale that they use to make these judgments. Additional insights into the design process can be gained and the interactive checklist can be revised to improve its user-friendliness. The knowledge engineer should determine if the interviews are to be conducted individually or in a group setting.

Steps 8-9. *Assess the Need for Supplemental Data Collection.* An interactive checklist can potentially be created without the need for supplemental field data collection or forensic investigations. However, Mason has advocated that knowledge based on the causal relationships related to design features can be gained from forensic investigations. [11] This effort would be devoted to adding checklist items that would not have been identified from earlier steps. Therefore, these investigations should be conducted at sites that have the greatest potential to produce new knowledge.

Step 10. *Conduct Forensic Investigations (if necessary).* Forensic investigations were covered in detail in chapter 6.

Step 11. *Develop Prototype.* This step would be to develop the working prototype for the selected situation of interest. This prototype should incorporate the findings from the interviews with the safety experts, the interviews with the design experts, and the forensic investigations.

AUTOMATED REVIEW FUNCTION DEVELOPMENT

Developing the specifications in geometric design units of measure that quantitatively define a problematic design situation constitutes the greatest challenge to developers of the DRC automated review function. Knowledge acquisition for the automated review focuses on the following three items:

- **Selection of the problems.** To maintain a manageable scope of work, subsequent knowledge acquisition efforts should focus on a selected number of emphasis areas. The actual selection process is described further in the experimental plan (appendix A).

- **Defining the variables or parameters of the problems.** Table 15 lists examples of data requirements (variables) for each problem emphasis area. The complete set of design features that describe the problem should be listed before knowledge acquisition begins. Some variables may be added with additional passes at the knowledge base. Additionally, many problems will be further defined by traffic volume parameters or characteristics. In other words, some situations may become problematic only when the traffic volumes fall within a given range.

- **Developing the specifications of the problems.** The next step is to develop the numeric thresholds that, when exceeded, display a flag in the CADD plan view. This task may include an examination of minimum design standards to determine where standards have been met but an accident problem exists. The resulting program will function similarly to the Policy Review Module, which raises flags when design policy is violated. Many issues related to specifying the problems are discussed in chapter 4.

As opposed to reminding a designer to consider the safety of certain design situations, this tool actually identifies (i.e., flags) the problem, based on a set of predefined numeric thresholds. For example, where sharp horizontal curves are preceded by tangent downgrades, the rules would define threshold values for grade, length of tangent, degree of curvature, length of horizontal curve, and superelevation. Where the thresholds are exceeded, a flag would automatically be raised. Illustrative threshold values might include the following:

- Grade ≥ -3 percent.
- Length of tangent ≥ 150 m (500 ft).
- Degree of curvature ≥ 5 degrees.
- Length of horizontal curve ≥ 30 m (100 ft).
- Superelevation < 0.10.

The program would compare these threshold values against those found in the CADD-based data. At locations where combinations of these thresholds are violated, a flag is raised in the plan view to alert the user about a potentially safety-deficient location.

A schematic of the proposed approach for the development of the DRC automated review function is shown in figure 18. A more detailed presentation of the knowledge acquisition process is illustrated in figure 19. An overview of this process is presented in this section, with selected steps discussed further, as necessary. Each step is more thoroughly described in the experimental plan in appendix A. The recommended process consists of the following steps:

Step 1. *Identify Potential Problem Emphasis Areas.* The first item would require that the FHWA, in concert with the IHSDM TWG, select problem emphasis areas. Due to the magnitude and variety of design situations encountered on two-lane rural roads, a tiered approach is recommended for the development of the DRC expert

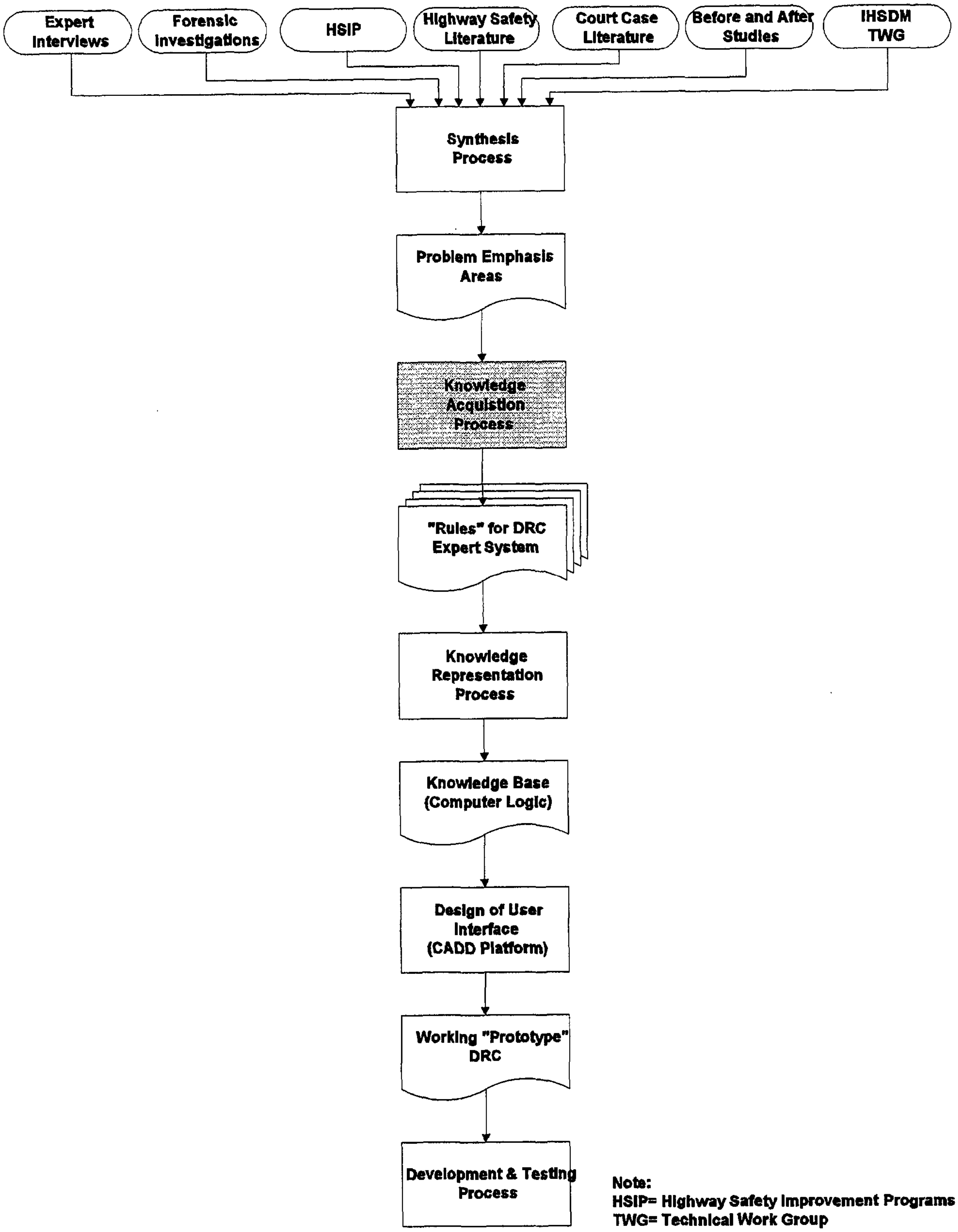


Figure 18. Proposed development process for the automated review function.

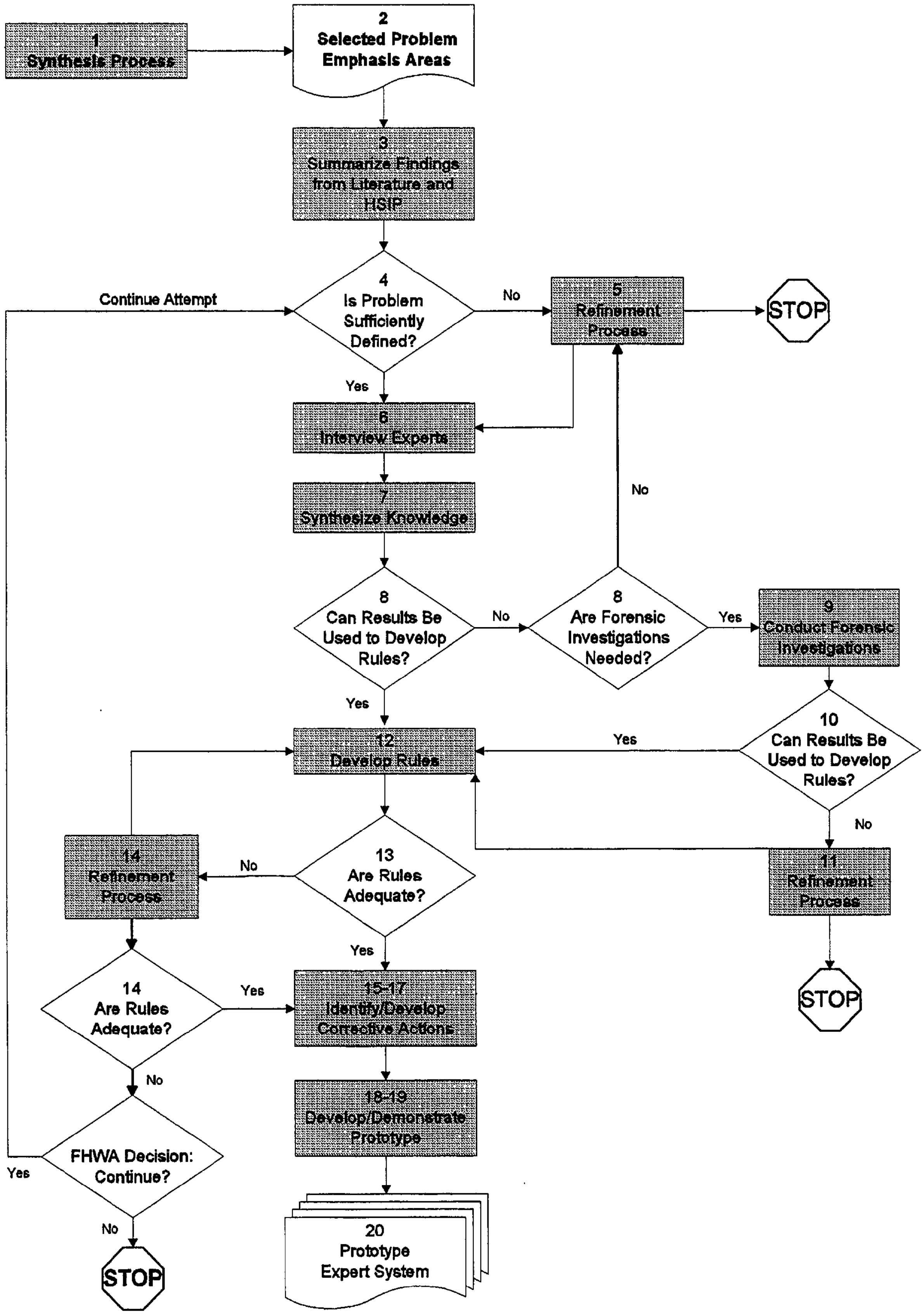


Figure 19. Proposed knowledge acquisition process for the automated review function.

system. Prioritized rules that define the geometric design, or heuristics, are developed for problematic combinations of geometric design elements. The situations judged to be the most problematic should have the highest priority. Then, subsequent effort should be devoted to other situations.

Step 2. *Select Problem Emphasis Areas for More Detailed Investigation.* The problem emphasis areas are likely to include the following three types of situations:

Type A Situations: Situations in which the combinations of design elements are well recognized as a problem, but there is no consensus as to the geometric specifications that constitute the problem. One example is a sharp horizontal curve preceded by a steep downgrade. The objective of the interviews with the experts would be to develop the geometric specifications that establish either: (1) how to prompt consideration of the element through the checklist, or (2) when to flag a situation.

Type B Situations: Situations in which there is some debate about whether the combinations of design elements are problematic. For example, 4:1 sideslopes may be adequate for a majority of cases. However, some researchers have argued that they result in an unacceptable proportion of rollovers. The objective of the interviews would be to define the roadway and geometric conditions for which 4:1 sideslopes expose drivers to unacceptable risks.

Type C Situations: Situations that are broad in scope. Examples would include: roads with narrow or no shoulders, and combinations of horizontal and vertical alignment. For these problem emphasis areas, there is a need to define the problem better before the development of the geometric specifications should even be attempted. The objective of the interviews should be to develop a subset of specific problem situations. Then, a second round of interviews with the same experts, or with a different panel of experts, could be conducted for each specific problem situation, to develop the geometric specifications.

Step 3. *Compile Relevant Findings From Accident Research Literature, Highway Safety Improvement Programs, Safety Audit Literature, and Before-and-After Studies.* Determine how they relate to specific geometric design elements. Draw conclusions as to how the findings could be translated into heuristics for the knowledge base. Summarize these efforts in a working paper.

Step 4. *Is the Problem Sufficiently Defined Such That Rules Can Be Developed?*

- If yes, go to step 6.
- If no, go to step 5.

For example, Type A situations, described in step 2, are problem emphasis areas for which rules can be written by interviewing experts and developing a consensus. However, this is not the case for Type C situations (also described in step 2). More detailed definitions will be needed for Type C situations before rules can be developed.

Step 5. *Refine the Definition Such That Rules Can Subsequently Be Developed to Describe the Problem.* Determine if the revised definition is now adequate. If the revised definition is still inadequate, stop, and accept the fact that rules cannot be developed for this problem area.

An example of this type of problem area might be horizontal curves without spiral transitions. There is still much debate over the benefits of using spirals. Moreover, it is unlikely if the conditions can be specified to define when the absence of a spiral is unacceptable from a safety perspective.

Step 6. *Identify Candidate Experts, and Determine Their Level of Knowledge Related to Selected Problem Areas.* Assign experts to specific problem areas and conduct the interviews. The contractor would interview groups of at least five different experts selected for each problem emphasis area. It is recognized that adequate specifications may not be developed from the interview process. For some situations, there may be either significant disagreement between the contractor and outside experts, or inadequate knowledge.

Step 7. *Synthesize the Knowledge Acquired.*

Step 8. *Assess the Knowledge Acquired.* Can the results can be used to develop the rules?

- If yes, go to step 12.
- If no, are forensic investigations at specific sites warranted?
    - If yes, go to step 9.
    - If no, can additional refinement improve the situation?
        - If yes, return to step 5.
        - If no, stop, and accept the fact that rules cannot be developed for this problem area.

Step 9. *If the Decision Is Made That There Is Utility to Conducting Site Investigations, Then Conduct Forensic Investigations.* Two viable approaches could be taken to complete these investigations. The first would be a strategic approach in which the situation would be defined to the greatest level of detail possible, and the contractor would then visit only those types of sites that have experienced the highest accident experience. For example, consider that the situation is an intersection at or just beyond a crest vertical curve. Efforts would be made to identify candidate intersection sites with tangent approaches and vertical curvature within 152 m (500 ft) on the major road.

The second investigative approach would be an exploratory approach in which high-accident intersection sites would be identified and analyzed. The types of sites visited could therefore be more robust than the group generated by the first approach. For example, the sites could include a greater variety of approach alignments. It is recommended that the exploratory approach be employed.

Some have argued that detailed investigations be conducted only at fatal crash sites, or at sites where crashes with severe injuries occurred. The selection criteria for this alternative approach would be individual crashes, rather than sites with high accident experience. The alternative approach would involve identifying locations where specific crashes (e.g., fatal) have occurred, and then conducting a forensic investigation at that specific site. Of course, this approach should also involve a review and analysis of all other crashes reported at or near that location over a specific period. This alternative approach is strongly discouraged. The basis for selection should be site-dependent, not crash-dependent. Fatal and severe crashes could be the result of unusual conditions that are beyond the control of the designer (e.g., type and use of seat belt/restraint systems, drunk drivers, type of vehicle, weather conditions, impact speed, etc.). Causal relationships are likely to be much stronger if a pattern of crashes can be established at sites that are routinely identified as having crash histories higher than the expected norm.

Step 10. *Assess the Knowledge Gained.* Can the results be used to develop the rules?
— If yes, go to step 12.
— If no, go to step 11.

Step 11. *If the Knowledge Is Still Insufficient, Determine if Additional Investigations or Interviews Are Needed to Refine the Existing Data or Knowledge.* If additional investigations or interviews do not produce the needed data, stop, and accept the fact that rules cannot be developed for this problem area.

Step 12. *Develop Rules to Flag Problems.*

Step 13. *Review Rules With the IHSDM Technical Work Group (TWG) and Determine if the Group Concurs That the Rules Are Now Adequate.*
— If yes, go to step 15.
— If no, go to step 14.

Step 14. *If the Rules Are Inadequate, Refine/Revise Them Appropriately, According to Suggestions Received From the TWG.* If the rules cannot be refined or improved, then the FHWA must determine if further research is needed, or if the effort should be abandoned.

Step 15. *Develop Illustrative Examples of Formats for Corrective Actions (if required).*

Step 16. *Determine Users' Preferred Format and Content for Corrective Actions.*

Step 17. *Identify the Most Appropriate Corrective Actions for Each Problem.*

Step 18. *Develop a Prototype*. For example, a prototype can be developed first for at-grade intersections, especially those at or near horizontal and vertical curves, which were identified by both State personnel and experts as worthy of attention. After the prototype has been beta tested by IHSDM users and refinements have been made, the expert system can be enhanced to include other combinations of elements. Then, in subsequent efforts, the expert system can be further expanded to include situations that are generally not regarded as hazardous in either severity or magnitude, such as hidden dips, or short tangents between reverse curves.

Step 19. *Demonstrate the Prototype to the TWG (users).*

Step 20. *Assess the Methodology and Develop Recommendations for Improvement, the Feedback Loop, and a Process for Continued Enhancement.*

Step 21. *Implement the Feedback Loop.*

ALTERNATIVE KNOWLEDGE ACQUISITION PROCESSES

Other processes could be employed to develop the expert system. These include the following.

- **Exploratory Process Employing Only Forensic Investigations**. The interested reader should see other references for more details.[11,25]

- **Formal Tasking Approach With Expert Designers**. This would be a more traditional approach to the development of an expert system. The process is illustrated in figure 20. Although the advocate and the user would have a role in the development, the primary contributors would be the knowledge engineer and the expert(s). They would have to interact and work well with each other during this process. The proposed process would require the knowledge engineer to observe how the expert designer works within his environment. Expert designers should concurrently be involved in the design of multiple two-lane rural-highway projects, preferably working in a supervisory capacity. Whenever the designer has a need to review the design plans (at the project planning, preliminary engineering, or final design stages), the knowledge engineer should question the expert. The goal is to document the underlying reasoning for design decisions, the specific items that require attention, and the method for checking combinations of design elements, among other matters. In this way, the knowledge engineer can extract the knowledge needed to create heuristics. This method may be most appropriate for the development of the interactive checklist.

- **Before-and-After Improvement Data**. The DRC knowledge base could be restricted only to situations where well-designed before-and-after studies concluded that the implemented treatments were effective. Heuristics could then be developed to scan the proposed design to identify situations that are similar to the "before" geometric conditions. Then, the treatments implemented and

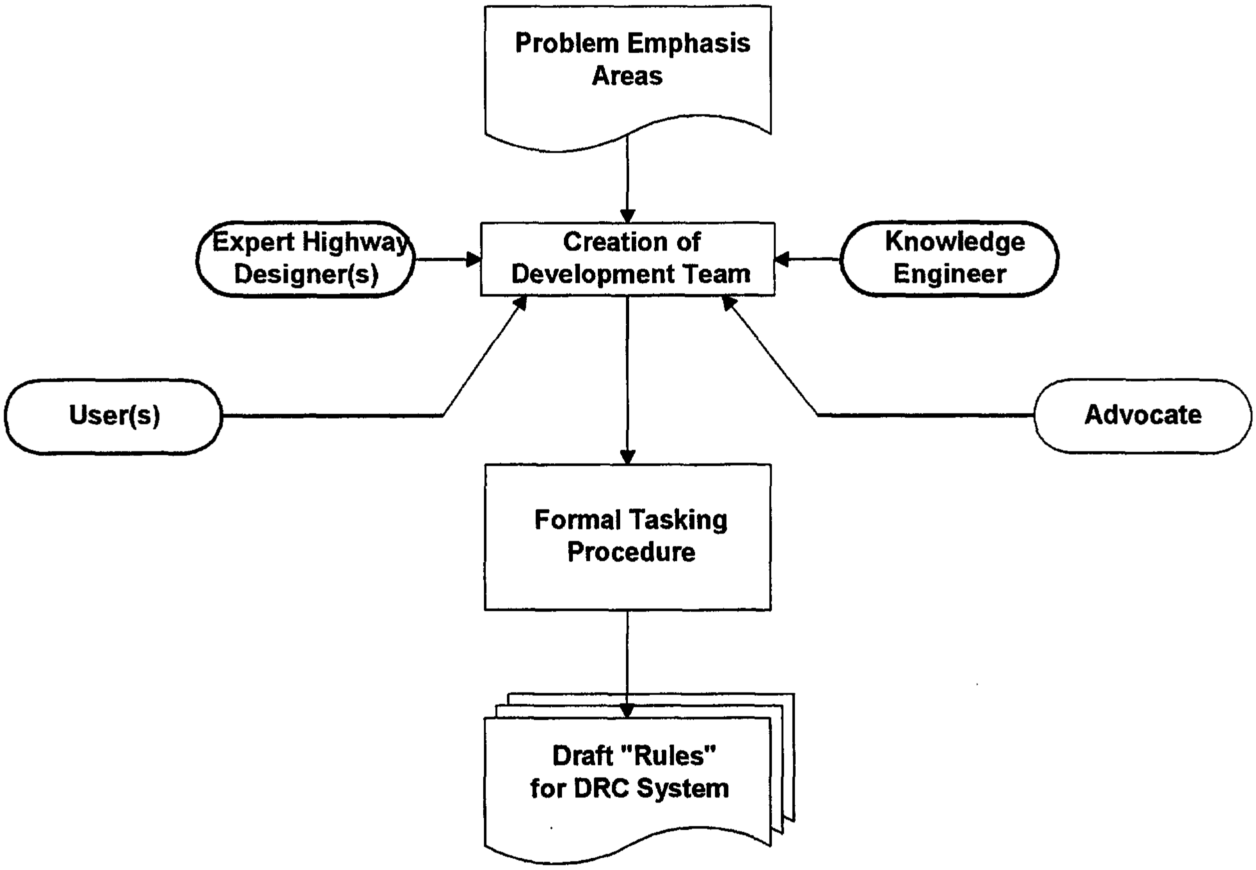


Figure 20. Alternative knowledge acquisition process for the DRC prototype.

the "after" conditions could be translated into "suggested corrective action" screens.

- **Use of Tort Liability Literature Only**. If the finding in the court case documentation was the geometric design contributed to the crash, then the geometric specifications for that site would be worthy for inclusion in the DRC knowledge base.

CAVEATS

Several system prerequisites were observed to impose constraints on the effort to develop an approach that would lead to the creation of the DRC knowledge base. These constraints stem from the conceptual requirements outlined by the FHWA for the DRC prior to this research being initiated.

First, as was noted earlier, the DRC will be developed as an expert system. The body of literature on expert systems, which was reviewed for this feasibility investigation, clearly indicates that a key role is played by the knowledge engineer who has experience in both knowledge acquisition and knowledge representation. The knowledge engineer essentially works with one or more experts to extract their knowledge, and then translates that knowledge into a set of rules that can be incorporated into a software program. For this feasibility study, there was no knowledge engineer on the research team. The scope of this research project was not to develop a prototype expert system, or even a first pass at the knowledge base. Rather, the objective was to investigate and assess alternative methods that could subsequently be employed (by others) to develop the knowledge base. A knowledge engineer was originally deemed not to be necessary. It should therefore be understood that the findings and conclusions do not reflect the perspectives of a knowledge engineer who has developed expert systems. Furthermore, it should be recognized that a knowledge engineer may determine that alternative method(s) are more appropriate.

Second, there needs to be a clear distinction between other expert systems developed for transportation engineering purposes and the vision for the Diagnostic Review Component of the IHSDM. In general, the expert systems reviewed for this project were systems devised to operate as self-contained, stand-alone programs. These included expert systems to help select the appropriate speed limit, a system to determine possible accident causes based on crash type and other relevant parameters, and an expert system to aid in the selection of appropriate signing for horizontal curves. For these systems, all input data were provided interactively by the user. As opposed to the DRC, there was no need to import data from another source, or to interface with data in another environment, such as CADD. All required inputs were to be provided by the user. Consequently, the knowledge engineer did not need to know CADD, nor understand how lines and points in a CADD drawing could be analyzed by an expert system. For the DRC expert system, the knowledge engineer must consider how to utilize the types and formats of the data resident in the CADD environment, so that the user need not reenter data unnecessarily.

Third, one key to developing an effective knowledge acquisition method is to successfully define the problems that will be addressed by the expert system. The research team had some difficulty in defining the specific problems that will be addressed by the DRC. Other expert systems have employed either a decision-tree approach (e.g., select the most appropriate speed limit from a limited set of choices) or a diagnostic approach (e.g., identify the most likely cause(s) and treatment(s), given a set of crashes exhibiting certain patterns). The objective of the automated review is to identify potentially safety-deficient combinations of geometric elements/features from a CADD-generated plan and profile of the road alignment. Compared with the functions served by other expert systems in transportation engineering, this objective is far more ambitious, and therefore more difficult to achieve.

Fourth, in the effort devoted thus far, the underlying assumption was that if the problem can be identified, then the heuristics, i.e., the computer logic and source code, can subsequently be created. The focus was on problem definition, and the sequence for development was:

Problem Emphasis Area → Problem Definition → Specification of Input Data Requirements → Development of Heuristics

Yet, no constraints were ever placed on the development of the heuristics. In this report, very little attention has been devoted to the reverse logic — devising the expert system based only on available data. The sequence for development would be:

Available Data → Problem Definition → Development of Heuristics

Given that an initial version of the PRM is under development, some consultation with its developers is appropriate. Their experience should provide valuable insight into the computer logic and source code required to integrate the system with CADD-based data. For example, the PRM developers could be asked, "For what design guidelines were they able to develop the necessary heuristics? In addition, for what design parameters were they not able to develop the necessary heuristics?" The answers to these questions may shed insights on what is possible within the context of the DRC.

For the DRC, the available data would include data that can be extracted from CADD plus additional data that can simply be entered by the user. If the development process is constrained to available input data, then questions pertinent to the automated review are:

- How can we utilize the available data to check the design to flag potential safety deficiencies?
- What should be checked at each major phase in the design process, e.g., project planning/scoping, project development, preliminary engineering, and final engineering?

Fifth, this report has outlined two distinct features of the DRC: an interactive checklist and an automated review. These concepts have been proposed by FHWA staff, and by Paniati and True.[2] Although the first feature was not originally envisioned by the research team, an attempt was made in this report to consider both functions. Obviously, the two features imply a drastically different focus for subsequent knowledge acquisition efforts. The second feature requires a much more ambitious knowledge acquisition effort, because developers must actually "write the rules" that define problematic design situations. The term "define" implies that specifications are written in geometric design units of measure such that the problems can be flagged automatically, using CADD-based data. Several sections in this report have discussed the obstacles and difficulties that could be associated with this effort.

In contrast, the interactive checklist does not depend solely on any design specifications. Here, the developers must establish a list that allows the user to consider potentially problematic situations. The goals of the interactive checklist and automated review are the same. Assuming checklist items (flags) are addressed, the result is a safer, more efficient design.

Table 16 summarizes the major differences between the two features proposed for the DRC. The fact that the automated review relies on quantitative guidelines has been frequently noted in this report. A second difference is the CADD interface. The interactive checklist could operate outside CADD, since data may be entirely user-supplied through a set of interactive questions. A basic tenet of the automated review is that it will contain help screens that explain the reason for a flag, and it will offer recommended courses of action. Help screens may or may not be incorporated into the interactive checklist. The automated review may require additional user input, including traffic data or design values that cannot be derived from the CADD plan.

Table 16. Comparison of the interactive checklist and automated review.

System Requirement	Interactive Checklist	Automated Review
Relies on quantitative design specifications.	No	Yes
Must operate within CADD.	No	Yes
Provides recommended courses of action through 'help' screens.	Yes or No	Yes
May require additional user input to execute program.	Yes	Yes or No

Noting the significant differences between these features, the research team was faced with two choices when drafting the experimental plan for future research: (1) write two plans to develop each feature exclusively, or (2) incorporate both features into a single plan, so that one or both features could be pursued in the next effort. Knowledge acquisition for the automated review is envisioned to be a much more difficult and ambitious project, due to the complex nature of defining problematic situations. However, many tasks necessary to the development of the interactive checklist are similar to those devised for the automated review. Therefore, the research team chose to write a single experimental plan (appendix A) that focuses on the automated review, with selected tasks that could be simplified to develop the interactive checklist. Where appropriate, recommendations that apply to one feature or the other are noted. Thus, the FHWA can modify the research plan so that it focuses on the development of one or both functions, according to its preferences.

Another option available to the FHWA is to develop the interactive checklist as an initial phase toward constructing the automated review. Since the checklist is less ambitious, the chance for successful development of a working prototype is increased. With time, the intelligence level of the checklist could be increased to allow it to identify elements of the design and prompt the user with only targeted, pertinent questions. This could lead to further enhancement of the checklist through beta-testing and continued knowledge acquisition. In addition, the checklist items could be refined to provide more-effective help screens. As the interactive checklist gains the capability to identify elements of the design, further specifications could be written to allow the program to distinguish specific design features as either adequate, or potentially safety-deficient. Thus, in subsequent development efforts, the interactive checklist could evolve into an automated review. This option is recommended by the research team.

Sixth, the proposed approach does not reflect findings from current research, i.e., Mason's review of tort liability literature or Harwood's before-and-after study of intersection improvements. It is hoped that the key findings from these studies can be incorporated into subsequent efforts. Despite these limitations, the experimental plan in appendix A is offered to the FHWA for consideration.

SUMMARY

This chapter provided a summary of the problem emphasis areas developed through an investigation into four knowledge acquisition methods for the DRC knowledge base. The results, summarized in table 15, list the automated review and the IHSDM module data requirements that are most closely associated with the related design features. Table 15 also suggests that many emphasis areas may be addressed by other modules, while the FHWA may need to decide the appropriate module for still others.

Proposed knowledge acquisition efforts for the interactive checklist and the automated review, respectively, were outlined. For the interactive checklist, this effort focused on the content, intelligence level, and specifications level for elements in the knowledge base. An 11-step process was outlined for the development of an interactive checklist. For the automated review, the focus was on the selection of problems, the identification of variables or parameters that define the problems, and the specification of the problems. A more complex, 21-step process was outlined for the automated review function.

In addition, four alternative knowledge acquisition processes for the DRC were reviewed. Potential caveats for developing the DRC were discussed. These include the primary DRC requirements, such as an expert systems approach and the CADD interface requirement. To conclude chapter 9, the differences between the interactive checklist and the automated review function were discussed. Recommendations and comments were made regarding the selection of the concept to pursue in the next research effort.

CHAPTER 10. RECOMMENDED RESEARCH AND CONCLUSIONS

This chapter presents recommended research that should be undertaken to continue the development of the Diagnostic Review Component. Conclusions are also presented at the end of the chapter.

RECOMMENDATIONS

It is recommended that the FHWA conduct research on the following two topics:

- **Development of an Empirical Review Module (ERM).** This is essentially a renaming of what has been referred to in this report as the Diagnostic Review Component (DRC). It is also recommended that the ERM be further expanded to incorporate general, qualitative, AASHTO design guidelines. The current FHWA development plan for the Policy Review Module (PRM) calls for it to be based solely on quantitative design criteria in the *AASHTO Green Book*,[9] with the capacity to be tailored to incorporate additional quantitative guidelines from individual State design manuals. However, this means that the qualitative guidelines that appear in the *AASHTO Green Book*[9] will not be addressed by any of the IHSDM modules.

- **Development of a non-CADD-based expert system.** This system will diagnose design-related causes of existing crash problems at specific locations and will aid in the selection of appropriate and cost-effective improvements. This expert system could then be called an accident diagnostic review tool, which is a more appropriate description. Essentially, this expert system would attempt to diagnose the causes of accidents that occur on existing roads. The program would use accident data, including crash frequencies, rates, patterns, collision types, and severities, among other variables, to determine the "symptoms" at a location. Thus, the term, "diagnostic review" is more applicable to this function than the expert system that has been discussed throughout this report.

More details on the specific recommendations are presented in the following paragraphs.

Develop a Preliminary Knowledge Base and a Prototype Expert System

It is recommended that research efforts to develop the preliminary knowledge base and a working prototype expert system be continued. The proposed process was described in chapter 9, and an experimental plan that could serve as the basis for a subsequent FHWA research project on this topic is presented in appendix A. Chapter 9 presents a set of problem emphasis areas that should receive consideration in the development efforts. The next research effort must produce a prototype that can subjected to the scrutiny of FHWA staff, the IHSDM Technical Work Group, and other potential users. Future efforts can then focus on refining and expanding the prototype.

It is highly recommended that the modular structure of the IHSDM be revised again to segregate the Diagnostic Review Component from the Accident Analysis Module (AAM). The DRC is intended to function as a design review tool, and thus, it more closely corresponds to the Policy Review Module. Elements of the knowledge base cannot be considered design policy, and therefore the DRC should operate separately from a policy review. In addition, accident prediction models within the AAM generate values that can be used to directly compare the safety of two or more design alternatives. The DRC is intended for use in the preliminary design stage when the project plans have been drafted with CADD software. The AAM is intended for use in the planning stages when existing accident data are reviewed to address potential safety concerns within the project limits. Thus, the two functions have little in common. For ease of understanding of potential users, it is recommended that these two modules be segregated. For clarification purposes, the Diagnostic Review Component should be called the Empirical Review Module. This has a side benefit in that an Empirical Review Module (ERM) would become an "equal" partner with the other IHSDM modules, and not a subcomponent of another module. It should be understood that the despite this recommendation, the term DRC has been used throughout the report, for consistency.

Two concepts for the DRC have been discussed throughout this report: an interactive checklist, and an automated review. The strengths and weaknesses of each approach have been well documented in previous chapters of this report. Knowledge acquisition methods could be similar for either approach, but the end results are vastly different. The automated review represents a much more ambitious effort, since it will be difficult to define problem emphasis areas such that they are properly flagged with a CADD drawing. The research team recommends that the FHWA decide which approach is most appropriate for the IHSDM. This decision should be made prior to awarding the contract for developing the expert system, so that the developer is fully aware of the expected capabilities of the prototype. The experimental plan in appendix A should be modified to suit the chosen feature.

Expand the ERM to Incorporate General Nonquantified AASHTO Design Guidelines

It is recommended that the ERM be expanded to include general guidelines from the *AASHTO Green Book*. There is currently no provision for incorporating qualitative guidelines into any of the IHSDM modules, due primarily to the difficulty of establishing accepted design criteria to define these situations. However, the overall safety of a design alternative would be greatly enhanced if designers had the ability to compare these qualitative design guidelines against their design plans. Perhaps the best way to illustrate these issues would be to examine three specific examples. Guidelines under "General Design Controls for Combination of Horizontal and Vertical Alinement" in the *AASHTO Green Book* include the following:

- Sharp horizontal curvature should not be introduced at or near the top of a pronounced crest vertical curve.

- Sharp horizontal curvature should not be introduced at or near the low point of a pronounced sag vertical curve.

- On two-lane roads, the need for safe passing sections at frequent intervals and for an appreciable percentage of the length of the roadway often supersedes the general desirability for combinations of horizontal and vertical alignment. In these cases, it is necessary to work toward long tangent sections to secure sufficient passing sight distance in design.[9]

With respect to the first and second bullets, if criteria could be established by a group of experts to define what constitutes "sharp" and what constitutes "pronounced," then it would be relatively easy to integrate the criteria into the DRC to flag the design locations where the errors occur. In the long run, this may reduce the possibility that this potentially unsafe combination of geometric design elements would be included in a design.

With respect to the third bullet, there are no quantified values for what constitutes a "safe passing section" (in terms of passing sight distance and length), the minimum "frequency" (in terms of sections per kilometer), or "appreciable percentage." Again, if a group of experts could define values for these variables and if these values were used for flagging potential problems in an expert system, then it would be possible to develop the appropriate heuristics. The following additional discussion on the frequency of passing sections is presented in the *AASHTO Green Book*:[9]

> "It is not possible to directly indicate the frequency with which passing sections should be provided on two-lane highways due to the physical and cost limitations. On almost all roads and selected streets some passing sections are provided in the normal course of design, but the designer's appreciation of their importance and his studied attempt to provide them usually can ensure others at little or no additional cost."

Consequently, it is important to convey to would-be users and experts that this effort would not be an attempt to establish new de facto design policies. Rather, it will provide quantified guidelines for an expert system attempting to enhance highway safety through improved design.

Of course, a model would need to be developed to determine the amount of available passing sight distance (measured from an eye height of 1.07 m (3.50 ft) to an object height of 1.3 m (4.25 ft)). A two-dimensional model to check stopping sight distance for vertical alinement has been developed by the University of Michigan Transportation Research Institute (UMTRI), and a prototype works within the IHSDM model. There are plans to develop a three-dimensional sight distance model for the IHSDM. A two-dimensional model to check stopping sight distance could be developed, but it would prompt users to enter offset distances to obstructions on the inside of horizontal curves. It is not inconceivable that models could be developed to: (1) check the design in terms of AASHTO passing sight distance, (2) identify safe passing sections in terms of AASHTO passing sight distance standards, and (3) calculate the percentage of the project where the available passing sight distance exceeded the standard. Alternatively, models could also be developed to check the design using the *Manual on Uniform Traffic Control Devices* (MUTCD) criteria for marking no-passing zones.

It is also recognized that the TWOPAS traffic module could be applied to identify areas where traffic operational problems attributable to insufficient passing opportunities are projected to occur. This could result in the identification of areas were the design should be revised to provide more passing opportunities. It would be desirable to circumvent the need to execute the IHSDM traffic module just to identify these situations. Inclusion of the rules of thumb within the DRC expert system would allow the designer to flag potential problems without employing other modules.

Develop an Expert System to Help Identify Existing Hazardous/High-Accident Locations and Select Appropriate Safety Improvements

During the course of this research, it became apparent that there were deficiencies and needs related to the identification of crash-related problems on existing roads. Several practitioners indicated that, in lieu of a module to identify potential safety-deficient locations within their design plans, they would prefer an expert system that performed the following:

- Identification of existing hazardous and/or high-accident locations.
- Determination of the design-related causes of patterns of reported crashes at existing spot-specific locations.
- Selection of appropriate and cost-effective safety improvements.

This expert system would be appropriate for the project planning or project scoping stage of the design process. While many States have developed their own procedures for highway safety improvement programs and highway safety evaluation programs, the development and dissemination of a computer-based expert system would serve as a useful complementary tool. It must be recognized that this is a stand-alone expert system and does not need to interface with CADD.

CONCLUSIONS

On the basis of the results of this investigation, the following conclusions are presented:

1. There is merit to developing a Diagnostic Review Component based on an expert systems approach. Based on discussions with experts and practitioners, there is support for an expert system that can be applied to the review of CADD plans and can help identify potential problems. This function may take the form of an interactive checklist or an automated review or both. Such a system would produce several benefits, including the following:
    - It would perform a thorough and consistent check of the design plans.

- It would facilitate the application of knowledge from the combined experience and insights of many experts.

- It would attempt to prevent accidents, rather than reduce the magnitude and severity of crashes after the problem location has manifested.

2. There is merit to developing another expert system that can assist the transportation professional. This non-CADD-based expert system would facilitate the identification of hazardous locations on existing two-lane rural roads, as well as the selection of appropriate safety measures for those locations. By definition, this type of expert system would perform a diagnostic function: to determine the nature or cause of an existing accident problem and to suggest a remedy.

3. The design-plan review process lends itself to an expert system. This conclusion assumes that experts can construct the necessary "rules of thumb" that will result in an efficient review of safety issues related to a proposed design. The system should aid the user by prompting consideration of issues that may have been overlooked, or providing guidance on the specific features that are potentially safety deficient.

4. Three primary knowledge acquisition processes are applicable to the development of the knowledge base for the DRC expert system. These are:

   - Structured and unstructured interviews.
   - Multidisciplinary site investigations.
   - Method of familiar tasks.

   These methods should be complemented in the initial passes at the data base by a review of accident research and safety-audit literature.

5. Knowledge acquisition and the development of specific rules will be two of the most difficult tasks in developing a DRC expert system. The expert system development team must consist of at least four members, who will have different roles—an advocate, a system user, an expert, and a knowledge engineer. For the automated review feature, the biggest challenges will be: (1) defining the point at which a combination of geometric design units of measure is indeed problematic in terms of safety and, therefore, should be included in the knowledge base, and (2) developing specifications in geometric design units of measure.

6. There are numerous potential threats to the successful development and the wide-scale use and acceptance of the automated review feature of the expert system. These include the following:

   (a) Threats to development of an automated review feature:

   - **Problem Definition**. The experts may be unable to develop sufficient geometric specifications for specific problems. This would pertain to: (1) situations where there are widely disparate opinions on the definition of geometric criteria, and (2) situations that cannot be defined. Examples of the latter category are:

— Situations for which the available sample is limited or nonexistent.
— Situations for which the experts have insufficient knowledge.
— Situations for which the forensic investigations are inconclusive.

For these situations, the contractor may need to combine specifications, select one set of specifications, or develop new specifications, using engineering judgment. Alternatively, it may become incumbent on FHWA to make final decisions about the inclusion of such situations in the DRC.

- **Cost**. The cost to conduct forensic investigations at specific crash sites is a time-consuming and costly process, with a less than 100-percent success rate.

- **Traffic Criteria for Problem Specification**. Certain combinations of geometric elements may become safety-deficient when the traffic volumes exceed some threshold. For example, 76-m- (250-ft-) long bypass lanes at T-intersections preceded by long downgrades may be adequate in terms of safety if the left-turning volumes are relatively low, or if the percent of trucks is relatively low. However, at higher volumes or a higher truck percentage, another site with identical design elements may experience an inordinately high number of crashes. Unfortunately, assessing the influence of traffic volumes on the magnitude or severity of a given geometric condition will be extremely difficult. Experts can attempt to define volume- or traffic-related thresholds. However, it is likely that they will have enough difficulty specifying the geometric characteristics, let alone specifying traffic thresholds. Similarly, forensic investigations will be based on a very limited number of sites.

- **Situations Not Easily Translated to Logic for a CADD-Based Expert System**. Another important issue is that the expert interviews and the forensic investigations may yield valuable knowledge related to the contributory effect of combinations of geometric design elements, but that knowledge may not be readily useable within the current IHSDM. This is possible because some lines and points within CADD software may not have any attributes and they therefore cannot be interpreted or used effectively within CADD. Consider the intersection with a bypass lane. The pavement edge lines have no attribute data. Consequently, CADD software currently has no way of recognizing that they define the edge of the travel way, as opposed to the edge of the paved shoulder. Thus, the length of the taper, the width of the bypass lane, the proximity to roadside objects (such as guardrail), and the length of the bypass lanes currently cannot be extracted directly from the CADD data file. For this situation, a series of questions will need to be posed to IHSDM users in order for the DRC to apply the logic properly to assess the adequacy of bypass lanes. This limitation should be recognized and understood by FHWA when it makes decisions on problem emphasis areas.

- **Prerequisite Skills of Knowledge Engineer**. As was stated earlier in this report, the IHSDM was conceived to operate within the CADD environment. Thus, all IHSDM modules, including the DRC, must utilize attribute data from a CADD file. Therefore, any discussion of an expert system for IHSDM must acknowledge that the expert system must operate within a CADD package. This might be a subtle distinction compared with other expert systems discussed in this report. Other expert systems such as HISAFE and VLIMITS are essentially stand-alone computer packages in which all data are directly entered by the user in response to prompts by the program. An IHSDM expert system must be able to extract data directly from the CADD file. Moreover, the logic rules that will be used to flag situations must be written in geometric design terms that are compatible with the attribute data in CADD. To develop an IHSDM expert system, the knowledge representation process will require an understanding of expert systems, CADD, and highway geometric design. It is unlikely that the knowledge engineer alone will have the skills and expertise in all these areas. Consequently, an expert system development team may be required.

(b) Threats to acceptance and use of the automated review feature of the DRC:

- **Credibility**. Transportation professionals may contend that the situation flagged is not a problem. There may be concerns that there are too many flags, or not enough flags.

- **Nontransferability of the Logic**. Problematic locations identified in one State may not be accident problems in another State. Alternatively, those particular combinations of design features may not even exist in other States.

- **Design and Format**. If the perspectives of a wide range of users are not adequately represented during the prototyping process, then the ultimate version of the IHSDM delivered to the design community may be compatible with current practices. The information also may not be optimally presented to users.

- **Existing Design Standards**. Many State personnel espoused a philosophy that if the standards were met, an acceptable level of safety was achieved. Their contention was that all safety problems on two-lane rural roads were substandard in some way, and therefore no additional rules were needed.

- **Improvement Justifications**. Many States justify improvements on the basis of the number of accidents reduced. They may have difficulty funding preventive measures.

7. There is a need to incorporate users into the expert system development process. This includes CADD users from the contractor's team who will be charged with developing the DRC. This is one primary reason that the experimental plan, presented in appendix A, proposes three meetings with the IHSDM Technical Work Group (TWG).

8. The review of the highway safety research literature and safety-audit material could be used as an initial knowledge source for the development of an interactive checklist, as well as to identify problem emphasis areas, structure expert interviews, and confirm interview results. State Highway Safety Improvement Programs could yield information on potential sites for field investigation. The annual reports, listing before-and-after accident data for completed projects, will also provide limited guidance. The results of this investigation suggest that the greatest reliance should be on expert interviews and field investigations, with other methods providing supplemental information as needed.

9. The requirements for integration with the CADD software are still unknown. It is uncertain what design features will have attributes at the time that prototyping efforts are initiated. For example, will the system recognize that one line type or color represents a pavement edge, while another represents an edge stripe? Currently, only limited information on horizontal alignment, vertical alignment, and typical cross sections can be extracted from current CADD programs. It is hoped that advances will allow additional graphic information to be properly interpreted within CADD, with associated attributes of lines and points attached to the graphic information.

10. Based on the expert system development process, it must be recognized that the initial knowledge base to be developed in the next effort will be applicable only to a small set of problems, and will be rudimentary at best. Mature expert systems require at least three passes at the knowledge base.

11. The next FHWA-funded effort in the DRC development process should be extended to include the development of a working prototype. Along with other IHSDM components, the DRC could then be subjected to beta testing and the scrutiny of users.

APPENDIX A. PROPOSED EXPERIMENTAL PLAN

BACKGROUND

The FHWA has committed to developing an Interactive Highway Safety Design Model (IHSDM), which will be a tool that designers can use to evaluate the safety aspects of highway design alternatives, in a computer-aided design and drafting (CADD) environment. The IHSDM will consist of several modules that perform an automated analysis of the design plans at the request of the user. In its current state of development, the following modules are envisioned: Driver/Vehicle Dynamics, Design Policy Review, Design Consistency, Traffic Analysis, and Accident Analysis. Within the Accident Analysis Module (AAM), the current concept calls for three separate submodels, namely, the Roadway Accident Prediction Model, the Roadside Accident Prediction Model, and the Diagnostic Review Component (DRC).

OBJECTIVES

The objective of this research effort is to develop a first-pass knowledge base and a working prototype of the DRC for eventual incorporation into the IHSDM. The purpose of the DRC is to identify potential design deficiencies—notably, combinations of geometric elements and/or features that may individually meet or exceed minimum design standards, but in combination constitute a potentially problematic situation. The DRC will be an expert system, because its logic will be based on the knowledge and experience of skilled highway designers and traffic engineers. It is anticipated that the system will perform an automated review by flagging potential problematic situations and specific design deficiencies. In addition, the DRC will present the user with a set of potential corrective actions for each situation.

Two features of the DRC were described in this report—an interactive checklist and an automated review. It is important to note that this experimental plan is written for the development of the automated review knowledge base only. A systematic process to generate the knowledge base for the interactive checklist can be found in chapter 9.

The knowledge base to be developed under this contract will consist of specific rules that can be converted to heuristics for the expert system. The rules must describe a set of problematic situations in specific geometric design units of measure for successful integration into a CADD-compatible program. Specification of the problematic situations in geometric terms is likely to include quantifying the following:

- Cross-section characteristics, such as pavement and shoulder width.
- Horizontal alignment characteristics, such as length of horizontal curves, central angle, horizontal curve radius/degree of curvature, and superelevation.
- Vertical alignment characteristics, such as percent grade, length of grade, length of crest, and sag vertical curves.

- Sight distance.

- Design speed.

In addition, certain characteristics related to traffic may be necessary or appropriate, including the following:

- Existing or projected average daily traffic (ADT) on the segment.
- Existing or projected truck mix, as a percentage of the ADT.
- Existing or projected design hour turning-movement volumes for critical intersections.

SCOPE OF WORK

The scope of work pertains to geometric design situations on paved, two-lane rural roads only. This includes, but is not limited to, the following:

- Homogeneous roadway sections.
- Intersections.
- Driveways.
- Bridges.
- Terminals with interchange ramps.
- Transitions from two-lane to multi-lane undivided highways, and vice versa.
- Approaches to raised concrete islands in the median.
- Transitions from two-lane to median-divided highways, and vice versa.
- Railroad grade crossings.

CONTRACTOR TASKS

Task A. Convene Kick-Off Meeting with IHSDM Technical Work Group (TWG) and Select Emphasis Areas. First, the contractor shall review all documentation prepared on the DRC, including the following:

- This report.

- Documentation prepared by others on an investigation of geometric design problems extracted from tort liability literature and case files from State lawsuits. (Reference 24.)

- Draft report resulting from, "A Workshop on the Development of the Interactive Highway Safety Design Model (IHSDM) Accident Analysis Module," June 1995.

- Documentation prepared as part of a separate FHWA contract (Contract DTFH61-96-C-00055) related to well-designed before-and-after accident studies of intersection improvements.

- A series of articles on the IHSDM prepared by the FHWA and published in *Public Roads*.

The contractor shall then prepare for a kick-off meeting with the TWG, FHWA personnel, selected FHWA on-site contractors and invited consultants, and other contractors. The TWG consists of representatives from State DOT's and other potential users of the IHSDM. A TWG has been assembled to provide guidance on the type and format of information that the IHSDM presents to the users. The most recent meeting of the TWG was November 30, 1995. The purpose of the kick-off meeting is to:

- Reacquaint the group with the latest IHSDM developments and coordinate a demonstration of prototype modules.

- Outline the objective of this research, the experimental plan, and the intended role of the TWG at this and subsequent meetings.

- Solicit comments and develop a consensus on ten problem emphasis areas for subsequent development of the knowledge base. A list of potential problem emphasis areas is summarized in figure 21.

- Solicit input on the types of experts desired and, if appropriate, the specific identities of experts for subsequent interviewing.

- Solicit comments and discuss the specific criteria for determining when a problematic design situation or combination of geometric elements should be incorporated into the DRC knowledge base. Consider, for example, that a forensic investigation conducted at one site determines that a specific combination of geometric design elements contributed to a high incidence of severe crashes at that site. Is that sufficient justification for including the specifications for the site geometry into the knowledge base? If yes, then what about sites with similar geometries that are not high-accident sites? If no, what constitutes sufficient justification?

- Solicit input and discuss the level of specification required to define the problem situation. This includes specification of the geometric design and specification of possible traffic-related parameters. Consider the problem situation of a sharp curve preceded by a steep downgrade. The group of experts may have sufficient differences of opinion as to what percent downgrade constitutes "steep" and what combination of curve radius/degree of curvature, length of curve, central angle, and superelevation constitutes "sharp." How should the logic rules be written in order for the expert system to: (1) reconcile differences of opinion, and (2) define the situation so that it can be identified in a CADD plan and profile drawing?

The contractor shall make all logistical arrangements for up to five members of the research team and seven members of the TWG to travel to Washington, DC, and attend a meeting to be held at FHWA's Turner-Fairbank Highway Research Center in McLean, VA. The contractor shall coordinate with each member to ensure that his or her travel arrangements have been made. The contractor shall also arrange to pay directly for all airfare and lodging and/or reimburse attendees for their travel-related expenses.

COMBINATIONS OF GEOMETRIC DESIGN ELEMENTS AND FEATURES

- Intersections preceded by horizontal and vertical alignment changes.
- Intersections preceded by vertical alignment changes.
  — Sight-restricted intersections with tangent approaches located beyond crest vertical curves.
- Intersections preceded by horizontal alignment changes.
  — "Tangential" intersections at the beginning of flat horizontal curves.
  — Intersections within short, sharp horizontal curves.
- Combinations of horizontal and vertical alignment changes.
  — Sharp horizontal curves preceded by tangent downgrades.
  — Horizontal curves beyond crest vertical curves.
  — Short tangents between horizontal curves.
- Multi-lane, divided to two-lane road transitions with alignment changes.
- Multi-lane, undivided to two-lane road transitions with alignment changes.

SINGLE GEOMETRIC DESIGN ELEMENTS OR FEATURES

- Intersections.
  — Skewed Intersections.
  — Intersections without channelization.
  — Inadequate lengths or taper for turn lanes.
  — Lack of left-turn lanes.
  — Driveways in close proximity to intersections.
- Horizontal alignment.
  — Isolated sharp horizontal curves preceded by long tangents on level terrain.
  — Winding road sections with sharp interior curves.
  — Reverse curves without proper transitions of superelevation.
  — Horizontal curves without spiral transitions.
  — Horizontal curves with improper super elevation.
- Vertical alignment.
  — Sharp vertical curves.

Figure 21. Candidate problem emphasis areas.

No later than 2 weeks before the meeting, the contractor shall disseminate information to each member of the TWG, key FHWA HSR-20 staff, and personnel invited by FHWA to participate in this meeting, including on-site contractors. This information shall contain a detailed meeting agenda and shall explicitly define session objectives. The secondary purpose of this agenda is to provide all participants with the opportunity to evaluate the emphasis areas in figure 21. All questions regarding the meeting agenda shall be directed to the contractor.

Task B. Develop First-Pass Knowledge Base for 10 Problem Emphasis Areas.

Task B1. Summarize Findings From Task A Meeting. Based on the input received from the TWG, and in conjunction with FHWA HSR-20 staff, the contractor shall:

- Identify the 10 appropriate emphasis areas for the DRC prototype.
- Establish criteria to determine when a problematic design situation or combination of geometric elements should be incorporated into the DRC knowledge base.
- Determine the level of specification required to define each problem emphasis area (i.e., exactly how will the experts be asked to specify the problem?).

Task B2. Compile Relevant Findings From Accident Research Literature, HSIP Data, Safety-Audit Literature, and Before-and-After Studies. The contractor shall conduct an extensive review of the knowledge sources listed above to determine how each might relate to developing rules for the knowledge base. The review should focus only on the emphasis areas chosen in task B1. HSIP data refers to highway improvement projects where the "before" design elements correspond to the problem of interest. It also encompasses contacting designers and traffic engineers with extensive experience in the area of interest, to gain a better understanding of the problem, including the variables and parameters required to define it. The results should be summarized in a working paper that outlines specifically how the findings apply to the knowledge base and/or how they can be used to assist further knowledge acquisition methods (e.g., structuring expert interviews).

Task B3. Identify Experts, Solicit Participation of Interviewees, and Conduct Interviews. The contractor shall identify appropriate personnel to serve as "experts" for the purpose of providing detailed specifications of the problem emphasis areas. In expert systems jargon, this process is referred to as "knowledge acquisition." The contractor shall develop a questionnaire asking the candidate experts to assess their own perspectives and level of knowledge about each of the problem emphasis areas. In addition, the contractor should solicit the willingness of the candidate experts to participate in this study, and their availability to do so. It is recommended that a minimum of five experts be assigned to each problem emphasis area. Experts may have mutually exclusive backgrounds in traffic engineering, geometric design, or accident reconstruction, among others. It is the contractor's responsibility to determine the set of experts that most completely represents the knowledge needed to describe the problem. Based on their level of knowledge and willingness to participate, experts may be selected for multiple problems. Recommended interview procedures are outlined in another section presented later in this appendix.

Task B4. Assess Interview Responses and Determine the Need for Field Investigations. The contractor shall then review and analyze the responses received from the experts. Field investigations should be considered if any of the following are true:

- An insufficient number of experts can be identified for a particular problem emphasis area.

- The expert specifications lack sufficient agreement to permit their being combined into a single rule.

- The criteria and/or level of specification developed in task B1 has not been met.

The number and location of sites for field investigations should be identified with the assistance of FHWA HSR-20 staff.

Task B5. Conduct Multidisciplinary Field Investigations. For this task, the contractor shall identify a two-person multi-disciplinary team that has experience in the following areas:

- Highway Safety.
- Geometric Design.
- Traffic Engineering.
- Forensic Investigation of High-Accident Locations or Motor Vehicle Crash Sites.
- Human Factors.
- Accident Reconstruction (desirable, though not necessary).
- Highway Maintenance (desirable, though not necessary).

The team shall prepare for and develop procedures for forensic site investigations. Recommended site investigation procedures are outlined later in this experimental plan. The contractor should review papers by Mason et al. that appear in reference 8.

Task C. Develop Expert System Rules for Problem Location Identification. The contractor shall then integrate the findings of task B to develop "logic rules" for the expert system. This conceptual model will allow the DRC to "flag" the problem emphasis areas within a CADD-generated drawing. The logic rules will consist of geometric specifications of the problem and any other parameters that determine when a location is to be flagged (e.g., ADT, turning-movement volumes, percentage of truck traffic). Guidance for this task may be provided by those developing the Policy Review Module of the IHSDM, a similar effort with respect to the formatting of logic rules for application in a CADD-compatible system.

Task D. Convene Second Meeting of Technical Work Group (TWG) and Evaluate Expert System Rules. The contractor shall prepare for a second meeting of the TWG, FHWA personnel, selected FHWA on-site contractors and invited consultants, and other contractors.
The purpose of the second meeting is to:

- Solicit input and discuss the logic rules developed in task C. Based on the problem areas identified in the kick-off meeting, the group will provide comments on the adequacy of the rules and related parameters.

- Identify corrective actions corresponding to the mitigation of each problem. A problem identified by the DRC will be represented by an icon, such as a flag. Clicking on the flag will display a "pop-up" window, as shown in figure 7. The window will present the user with potential corrective actions specific to each type of flag.

At the second meeting, it is recommended that the draft rules be presented in both graphical format, perhaps accompanied by plan and profile sketches, and numerical format. Plan views that depict each problematic situation would greatly facilitate understanding by the TWG and FHWA. In addition, it is recommended that illustrative "windows" be created to convey the concepts for the suggested mitigating measures. At this second meeting, potential formats and contents for the corrective actions should be communicated clearly to the TWG, prior to expending effort on software programming and prototyping efforts. It is not necessary, however, that illustrative computer screens be developed for this second meeting. Input will be received from the TWG on desired and/or preferred formats and contents for the information. Computer screens can then be created after the meeting, in subsequent tasks, as part of the prototyping effort. The outputs will then be demonstrated to the TWG at the third meeting.

The contractor shall make all logistical arrangements for kick-off meeting attendees to return to FHWA's Turner-Fairbank Highway Research Center in McLean, VA. The contractor shall coordinate with each member to ensure that his or her travel arrangements have been made. The contractor shall also arrange to pay directly for all airfare and lodging and/or reimburse attendees for their travel-related expenses.

No later than 2 weeks before the meeting, the contractor shall disseminate information to each member of the TWG, key FHWA HSR-20 staff, and personnel invited by FHWA to participate in the second meeting, including on-site contractors. The information shall summarize the problem specifications formulated in task C and shall outline the objectives of the second meeting. This will provide group members with the opportunity to review the problem specifications (logic rules) and develop corrective actions in advance. All questions regarding the meeting agenda shall be directed to the contractor.

Task E. Refine Expert System Rules and Develop the Set of Possible Corrective Actions. As a result of the input received at the second TWG meeting, the problem specifications may need refinement. The contractor shall determine the extent of any refinement needed. This may include the adjustment of certain values, or the addition of new parameters. Experts who defined the original specifications may need to be contacted again for further information or clarification. For each problem area, the contractor shall identify the set of corrective actions that best represents the consensus of the TWG in task D. The contractor shall determine the optimal number and wording of suggested actions. The contractor shall then develop illustrative formats to convey this information to the user.

Task F. Develop a Working Expert System Prototype for the DRC. This task is referred to as "knowledge representation." The conceptual model of problem specifications and corrective actions will be translated into computer logic. The contractor shall develop a working prototype expert system using the logic rules developed for problem identification in task C and refined in task E. Each problem should have an associated pop-up window with the set of potential corrective actions developed in task E. FHWA HSR-20 staff should determine when the working prototype is ready for demonstration in task G.

Task G. Convene the Third Meeting of Technical Work Group (TWG) and Demonstrate the Prototype. The contractor shall prepare for a third meeting of the TWG, FHWA personnel, selected FHWA on-site contractors and invited consultants, and other contractors. The purpose of the third meeting is to:

- Allow the group to view and evaluate the DRC prototype. This will be done by presenting a CADD drawing that contains the design situation intended to be flagged by the system. The contractor will demonstrate the operation of the DRC and the format of the flags and pop-up windows for each problem emphasis area. Each member of the TWG will be given the opportunity to comment on the format of the information display and rate the "user friendly" nature of the program.

- Discuss future research efforts with respect to the DRC knowledge base and the addition of future logic rules and corrective actions. The TWG will be asked to identify means of further demonstrating and enhancing the DRC prototype.

The contractor shall make all logistical arrangements for attendees of the two previous TWG meetings to return to FHWA's Turner-Fairbank Highway Research Center in McLean, VA. The contractor shall coordinate with each member to ensure that his or her travel arrangements have been made. The contractor shall also arrange to pay directly for all airfare and lodging and/or reimburse attendees for their travel-related expenses.

No later than 2 weeks before the meeting, the contractor shall disseminate information to each member of the TWG, key FHWA HSR-20 staff, and personnel invited by FHWA to participate in the third meeting, including on-site contractors. The information shall outline the objectives of the final meeting and shall provide group members with the opportunity to generate thoughts about the DRC prototype and future research activities. All questions regarding the meeting agenda shall be directed to the contractor.

Task H. Evaluate Process and Recommend Modifications to Expand the Knowledge Base and Improve the DRC. After the task G meeting, the contractor shall develop recommendations for subsequent passes at the DRC knowledge base. Based on the work completed in tasks A through G, the contractor should be extremely knowledgeable about the needs and requirements of future research. Therefore, the contractor shall develop a modified systematic process of knowledge acquisition, knowledge representation, and prototyping of the expert system.

Task I. Prepare Draft and Final Reports. The contractor shall prepare an appropriate number (e.g., 10) of copies of a draft final report, which shall be submitted to the FHWA on or before the end of the 25th month after the contract start date. The report shall concisely document the development of the preliminary version of the DRC knowledge base and the prototype expert system. All reports shall be prepared in accordance with the *Guidelines for Preparing Federal Highway Administration Publications* (FHWA-AD-88-001), January 1988, as amended by Change 1, May 20, 1994. All reports or other documentation shall provide units of measure in the SI (metric) system with their English equivalents.

The contractor shall also prepare for and attend a meeting with FHWA officials at the Turner-Fairbank Highway Research Center in McLean, VA, within 1 month after the delivery of the draft final report. The contractor shall make a presentation of the results to FHWA at this meeting and shall also demonstrate the prototype DRC, which will have been revised to reflect the comments received at the third TWG meeting. In addition, the contractor shall present its findings on the evaluation of the process.

Within 30 days after delivery of the draft final report, the contractor shall receive the FHWA's technical review comments on the draft final report. The contractor shall revise the report to address those comments. Then, the contractor shall submit five (5) copies of the final report to FHWA for editorial review. Within 60 days after delivery of the final report, the contractor shall receive FHWA's editorial review comments on the final report. The contractor shall then address those comments and submit to FHWA a final, camera-ready copy of the final report; a diskette containing the files, prepared in WordPerfect 6.1 or later; and 20 copies of the final report.

RECOMMENDED INTERVIEW PROCESS AND PROCEDURES

This section documents the suggested interview procedures, based on experience from the interviews of experts and State DOT personnel. The purpose of the interviews outlined here is to extract information from the experts in order to define quantitative rules (in geometric design units of measure) for each of the chosen problem emphasis areas.

Expert Screening

Experts should include those individuals with at least 10 years experience in the areas of highway geometric design and traffic engineering, and/or accident reconstruction and forensic investigation. These experts could be State or local transportation agency employees, private consultants, expert witnesses, or research specialist. Experts chosen by the contractor should be selected based on their credentials and reputation in the transportation community.

Based on the list of selected problem emphasis areas selected after consideration of the comments from the IHSDM Technical Work Group (TWG), an initial questionnaire should be developed to assess each expert's level of knowledge in each of the chosen problem emphasis areas. This questionnaire will screen the experts to ensure that they feel qualified to define the problems and to determine these problem scenarios to which they could contribute valuable information. The questionnaire should be distributed to the experts, along with a letter inquiring as to the experts' willingness to participate in the study and their availability to do so. Also, at this time, the expert should be informed that if he or she decides to participate, he or she will be compensated for all time spent on the project. A description of the objectives of the interviewing effort and the DRC should also be included in this letter, as well as a discussion of what the interviewee might expect from the interview. In other words, the experts should be informed that he or she will be expected to quantitatively define, in sufficient geometric terms, specific design situations and combinations of geometric elements/features judged to be safety-deficient, not just simply discuss them. In doing this, the expert will be better able to assess his or her knowledge level in these areas.

Once the completed questionnaires are received, it is necessary for the contractor to decide which experts will be used to supply knowledge for each of the selected scenarios. The goal is to obtain information from five experts for each problem emphasis area. Experts may be used to define more than one problem.

Interview and Questionnaire for Rule Development

A second questionnaire should be designed for use during the structured interview. Each question should qualitatively define one of the selected problem scenarios and then follow with a discussion of variables that are necessary to define each problem quantitatively. In this interview questionnaire, the expert should also be permitted to provide any additional variables that were not first considered by the consultant. For example, consider that the selected problem emphasis area is, "intersections at or beyond crest curves." The variables that need to be defined could include: intersection skew angle, corner radii, distance from the curve apex to the intersection, approach grades, length of crest vertical curve, intersection sight distance (if not included in another module), horizontal alignment (if appropriate), design speeds, traffic volume (if known), among others. The questionnaire should ask the experts to define these variables quantitatively. Also, the experts should be asked if they believe there are any other variables relevant to the problem that need to be considered, thus opening up the discussion to other pertinent conditions that contribute to the problem. It is recommended that the knowledge engineer be involved in developing the questionnaire, to ensure that the information being extracted can be directly used in building the expert system.

The questionnaire should then be distributed to the experts, with the questions that address only the problem scenarios they were chosen to define. (Also, a cover letter should be included that fully restates the project and interview objectives.) A telephone call to each expert is suggested, to ensure that he or she has received the questionnaire and has given it some consideration. Also, during this call, a time may be set for the future phone interview pertaining to the issues in the questionnaire. If the expert has reviewed, and possibly even completed, the questionnaire prior to the formal telephone interview, the results of the interview will be more successful. In this way, the expert can give each problem more thought and will not be surprised by any questions during the interview. Also, any pertinent questions that arise while the expert is reviewing the questionnaire can be addressed directly during the interview.

It is recommended that, in cases where the expert is located in a geographic area where it is economically feasible to conduct the interviews in person, the interviews take place at the office of the expert. Budget must be taken into account here, and in-person interviews should be conducted only after a telephone conversation with the expert indicates that further knowledge could be gained through an office visit. It is believed that the in-person interviews encourage the expert to put forth greater effort and thought into the task at hand. Also, any relevant project or case-file information is more readily available at an in-person interview. This is particularly important for these types of interviews where quantitative variables and details are being defined.

When conducting interviews, the interviewer should probe the expert for detailed design information and variables and should keep in mind that, ultimately, quantitative rules must be developed for the problem scenarios. After the problem has been thoroughly discussed and defined, the interviewer should then inquire as to potential corrective actions or solutions. If the interview is in person, the interviewer should suggest that the expert prepare by gathering any necessary project or case files for review during the interview.

Upon completion of the interviews, it will be possible to determine which problem emphasis areas require further investigation through forensic/accident reconstruction investigations.

RECOMMENDED CLINICAL SITE-INVESTIGATION PROCESS AND PROCEDURES

The recommended process consists of the following steps:

1. Select the most appropriate HSIS State(s), which would be the State(s) that possess the best available data for the selected problem type. Develop criteria to identify potential candidate sites.

2. Identify potential candidate sites and create a potential candidate-site file, based on the problem (e.g., horizontal curves preceded by downgrades).

3. Merge 3 years of crash data with the potential sites, creating an accident-based file and a site/section-based file. Screen out selected crash types (e.g., animal crashes, pedestrian/bicycle crashes).

4. Calculate average annual accident frequencies and accident rates. Rank order the sites based on accident rates. Identify candidate sites with the highest accident rates. Create accident summaries for each site.

5. Review the latest photologs for each candidate site and determine its suitability. Generate photographs of the sites from the photologs. Create a final list of selected candidate sites.

6. Request hard copies of all police accident reports for accidents within the "zone of influence" of each site or section. Crash reports should pertain to the same 3-year time period used in steps 3 and 4.

7. Request copies of any as-built plans, CADD files, aerial photography, mapping, and information from Geographic Information Systems (GIS) that may be available from the State agency, for each selected candidate site.

8. Receive and review the hard copies. Prepare accident collision diagrams for all sites.

9. Receive and review mapping. Prepare a base map or sketch of the site.

10. Solicit traffic data and additional information about recent and/or scheduled changes for the sites from the local district engineers/administrators. Inquire about the history of the site, improvements that may have been considered, and other local conditions. Coordinate with the local contact about the purpose of the forensic investigations, the anticipated schedule, and any needs from local highway agencies.

11. Distribute the package of information on each site to a two-person multidisciplinary team and arrange to travel to the sites. Check long-range weather forecasts and consider seasonal factors. Assemble the data collection equipment, including stop watches, 35-mm camera, video cameras and videotape, measuring wheels, 100-m (30-ft) measuring tape, sight distance measurement devices (e.g., telescoping poles with marks to define heights of 15 cm (6 in), 1.1 m (3.5 ft), and 1.3 m (4.25 ft). Travel to the sites.

12. Conduct the site investigations. Develop hypotheses about the relative contribution of the geometric design to the crash problem. Develop a consensus conclusion about whether this situation should be included in the DRC knowledge base. Make a determination as to the need for follow-up field observations or traffic studies. Identify and discuss potential corrective actions that would mitigate the problem. (Details about the recommended procedures are discussed later in this section.)

13. Synthesize the results into draft rules for the DRC expert system. Develop appropriate heuristics to define how this potentially safety-deficient design situation can be flagged at the various stages of design (i.e., project planning, preliminary engineering, and final engineering). Determine the need for the replication of forensic investigations at other sites or in another State. Reassess the forensic investigation methodology and identify means to enhance the procedures.

With respect to the field procedures (step 12), it is recommended that the following be performed, depending on the type of site:

- Conduct a drive through the site. Drivers should traverse the situation in all directions. At intersections, the drive-through should include all approaches and all possible turns. Both investigators should conduct an independent drive-through, without passengers, and should place themselves in the mindset of a driver unfamiliar with the road or intersection. Commentary driving should be used with video camera to make a permanent record of the first pass.

- Perform an expectancy violation review and look for hazard detection and recognition problems. If appropriate, construct a hazard profile in accordance with Positive Guidance principles.[57] Determine the information-handling zones (advance, approach, nonrecovery, hazard, and downstream zones). Assess the information load, if it is felt that this may be a cause of certain crashes.

- Make unobtrusive observations of how local drivers maneuver through the site. These should be conducted for at least 15 minutes, preferably during periods when there are frequent vehicle arrivals. It is not necessary that these observations be made during peak hours. Consideration should be given to collecting these observations during the periods with the high-accident experience. It would be desirable to calculate accident rate by time of day, but accident frequency by hour/time of day can suffice.

- Take 35-mm photographs from all approaches, and from upstream positions both far and near of the site.

- If not available from as-built plans or other mapping information, collect field measurements of cross section and alignment. If necessary, "eyeball" the lengths and degrees of curvature for horizontal curves, points of vertical curvature, percent downgrades, and other crucial geometric design elements. Eyeball whether superelevation is present and if it is adequate.

- Prepare a condition diagram for each site, noting posted speed limits, traffic control devices (e.g., signs and markings), guardrail, utility poles, adjacent railroad tracks, trees, embankments and ditches, bridges, roadside billboards and signs, fixed roadside hazards, highway-condition hazards (such as pavement edge drop-offs and sudden cross-section changes), situation hazards, driveways, and intersections, etc.

- Measure and assess the available sight distance, especially the intersection sight distance across all quadrants from all approaches.

- Assess the pavement, shoulder, and roadside conditions. Investigate evidence of problems related to driver's speed and path decisions (e.g., skid marks, damage to roadside objects, evidence of erratic maneuvers).

- Determine the need for spot speed measurements and, if appropriate, collect data.

- Establish ideal speeds and paths. Determine actual speeds and paths. Compare ideal and actual speeds and paths.

- Develop a hypothesis about the potential cause for specific crash patterns. Make inferences about the contributory role of the geometric design. Compare the findings with those of other forensic investigators and draw conclusions.

LEVEL OF EFFORT AND COST ESTIMATE

The following disciplines and/or expertise are believed to be necessary for the successful completion of this project:

- Highway Safety.
- Geometric Design.
- Computer-Aided Design and Drafting.
- Highway/Traffic Engineering.
- Human Factors.
- Accident Reconstruction/Forensic Investigation of Motor Vehicle Crashes.
- Knowledge Engineering.
- Accident Data Bases.
- Statistical Analysis.
- SAS Programming.
- Support Staff.

It is recommended that the Principal Investigator (PI) devote a minimum of 35 percent of normal working time to this study. The estimated cost of this project is $600,000. This assumes $500,000 for the labor effort. For comparison purposes, the average labor rate for all categories, excluding the outside experts, was assumed to be $125,000 per person-year, and one person-year was assumed to be 1,920 hours. In addition, $32,000 was assumed for a consultants pool to compensate experts and other consultants for their time. This assumes 40 experts being compensated for 8 hours of their time at an average of $100 per hour.

The level of effort for this work effort is shown in table 17. The estimates are advisory. The hours estimated for the highway safety category are assumed to be the hours for the PI. It is also noted that the hours of the members of the IHSDM User's Group are not included in table 17. It was assumed that these individuals, who work for State highway agencies and the Federal Highway Administration, would not be compensated for their time by the selected contractor. However, their travel costs would be reimbursed by the contractor under this contract.

Table 17. Level of effort estimated by task.

Labor Category	Tasks										Total
	A	B	C	D	E	F	G	H	I	J	
Highway Safety	80	400	320	240	80	160	160	80	80	240	1840
Highway Geometric Design	40	240	160	160	64	120	40	40	40	160	1064
Computer-Aided Design	0	0	0	120	40	120	200	40	40	40	600
Traffic Engineering	24	160	160	160	40	160	0	40	40	160	944
Human Factors	24	160	160	160	40	160	0	40	40	80	864
Accident Reconstruction	24	160	160	0	40	40	0	40	40	40	544
Knowledge Engineering	24	160	0	160	40	160	320	40	40	80	1024
Accident Data Bases	0	0	120	0	0	0	0	0	0	0	120
Statistical Analysis	0	0	80	0	0	0	0	0	0	0	80
SAS Programming	0	0	80	0	0	0	0	0	0	0	80
Support Staff	40	40	40	40	40	40	40	40	40	160	520
Outside Experts	0	320	0	0	0	0	0	0	0	0	320
TOTAL	256	1640	1280	1040	384	960	760	360	360	960	8000

The costs for travel were estimated to be equal to $68,000. The assumptions used in developing the travel cost estimate are presented in table 18. It was assumed that the contractor's team would include three consultants/subcontractors who would have to travel to the contractor's office to participate in critical team meetings. It was also assumed that the PI, a key staff person, and up to three consultants/subcontractors would have to travel to Washington, DC, to participate in the IHSDM User Group meetings and a briefing to the FHWA after the delivery of the draft final report.

Table 18. Assumptions for travel costs.

Task	Description	Per Diem Costs	Transportation Costs	Total Travel Costs
A	IHSDM User's Group Meeting	7 people in the User's Group x 2 days x $100/day = $1,400. 5 people on the contractor's team x 2 days x $100/day = $1,000.	7 RT airfares @ $500/RT = $3,500. 5 RT airfares @ $500/RT = $2,500.	$8,400
B	Travel and Conduct 20 Interviews	1 person x 2 days/trip x $100/day x 20 trips = $4,000	20 RT airfare @ $500=$10,000	$14,000
C	Travel and Conduct Site Investigations at 40 Sites	2 people x 40 sites x 1 day/site x $100/day= $8,000	40 sites x 1 trip/5 sites x $500/trip x 2 people= $8,000	$16,000
D	Internal Team Meeting	3 people x 3 days x $100/ day = $900	3 RT airfares @ $500/trip= $1,500	$2,400
E	IHSDM User's Group Meeting	7 people x 3 days x $100/day =$2,100 5 people x 3 days x $100/day =$1,500	7 RT airfares @ $500/RT= $3,500. 5 RT airfares @ $500/RT= $2,500	$9,600
G	Internal Team Meeting	3 people x 3 days x $100/day = $900	3 RT airfares @ $500/trip= $1,500	$2,400
H	IHSDM User's Group Meeting	7 people x 3 days x $100/day =$2,100 5 people x 3 days x $100/day =$1,500	7 RT airfares @ $500/RT= $3,500. 5 RT airfares @ $500/RT= $2,500	$9,600
I	Internal Team Meeting	3 people x 2 days x $100/day = $600	3 RT airfares @ $500/trip= $1,500	$2,100
J	Meeting With FHWA	5 people x 2 days x $100/day =$1,000	5 RT Airfares @ $500/trip= $2,500	$3,500
Total		$25,000	$43,000	$68,000

PERFORMANCE PERIOD

The suggested period of performance for this research would be 30 months. A proposed schedule for the conduct of this study is shown in figure 22.

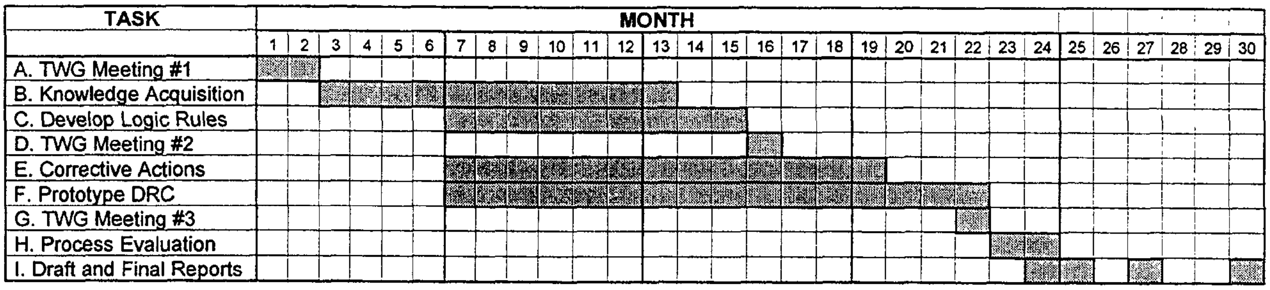


Figure 22. Proposed schedule.

APPENDIX B. HUMAN FACTORS INVESTIGATION: SELECTED RURAL-INTERSECTION SITES

METHODOLOGY

Accident patterns relating to the intersection geometric design were investigated at four selected sites in Minnesota. For each site, the following was provided: an accident summary sheet, individual police reports, and color copies of photographs of the major approaches to the intersection, extracted from a photo-laser videodisc system.

Accident Summary Sheets

Summary sheets were used mainly to determine the predominant characteristics in terms of ambient lighting, road surface condition, and time of day (night, rush hour), for the accidents at a given intersection. Other summary values, such as distribution by accident type and by manner of collision, were also shown.

Police Reports

Police reports were used to identify initiating events. Accidents were classified according to the initiating event, rather than the type of accident that followed. For example, a typical accident involved a vehicle trying to avoid a vehicle ahead that was stopped waiting to turn left. Whether or not these situations resulted in a rear-end collision, or in rollovers or other accidents due to driver attempts at avoidance maneuvers, all were classified as rear-end accidents, because the initiating problem was the following driver not perceiving a stopped left-turning vehicle in time.

Photologs

For each site, copies of photographs from a video photolog of the major road approaches to the intersections were obtained. These were used to determine lane markings indicating dedicated left- or right-turn lanes, determine the presence of buildings or other structures adjacent to the intersection, identify traffic and commercial signs adjacent to the intersection, and suggest sight-distance deficiencies that could be examined during the site visit.

Site Visit Preparation

Prior to visiting the sites, collision diagrams were prepared to identify the movements resulting in accidents. For each accident, the road condition, light condition, time of day, date, and ages of drivers involved were noted.

INTERSECTION ANALYSIS

In this section, a summary of the investigation results is provided for the four selected intersections sites visited over the period October 28 through October 31, 1996.

Site 12

This site consisted of the following:

- Three-legged intersection with bypass lane.
- Single leg on west side.
- Main road straight through intersection.
- Major ADT of 24,000 vehicles per day.
- Minor ADT of 2,500 vehicles per day.
- Average accident rate of 0.83 accidents per million entering vehicles.

Police Reports

The police report summary showed 16 accidents at this intersection, mainly daytime, on dry roads, with a peak at the noon hour. The predominant accident pattern involved northbound drivers stopped to turn left and being rear-ended by following drivers.

Photolog

The photo showed a large billboard, close to the major road and opposite the minor road, and a commercial building on the minor leg.

Site Visit

A bypass lane had been created through lane markings on the major road. The site visit indicated a fair amount of left-turning traffic. Given the high volume of traffic on the major road, drivers were sometimes stopped for an extended period of time waiting. During the brief observation period, one truck stopped for 20 s waiting to turn, and as many as three cars were observed in a queue waiting to turn. Several unsafe turns were observed. It appeared drivers were so anxious to remove themselves from a "sitting duck" position that they accepted very short gaps in the southbound traffic.

On the approach to the left-turn point, a large billboard attracts one's attention to the right and away from the main road just as traffic ahead may be slowing or stopping for the left turn. The high volume of traffic on the main road means that left-turning vehicles must wait in a stopped position. The minor road surface is not easily visible for northbound drivers. Although the billboard is an advertisement for the restaurant at the intersection and has an arrow pointing toward the intersection, the arrow is very thin and not at all obvious from a distance. Therefore, it does not help a driver become aware of the intersection. In one of the accident reports, a driver actually admitted to being distracted by the billboard just prior to rear-ending another driver.

Accidents

The 16 accidents reported at this intersection over a 2-year period included the following:

- 10 intersection crashes (rear-end major).
- 2 deer crashes.
- 3 other crashes (2 reversing drivers, 2 sideswipes involving tractor-trailer trucks).
- 1 unknown (the explanation given was such that it could not be determined whether the accident related to the intersection or not).

Site 17

This site consisted of the following:

- Y intersection.
- Rail crossing on minor leg of Y.
- Major ADT of 10,000 vehicles per day.
- Minor ADT was unknown.
- Accident rate of at most 1.62 accidents per million entering vehicles (although, the exposure estimate does not reflect side road traffic).

Police Reports

The accident report summary showed 12 accidents, with 7 potentially related to the evening rush hour, 10 on dry roads and 10 in daylight. Nine of the accidents were of the same type, namely a vehicle was stopped at the stop sign, started forward, and was rear-ended by a following vehicle when the first vehicle stopped again.

Site Visit

The problem causing the nine accidents at the stop sign was not immediately obvious. However, by driving the same path as the vehicles involved, it was determined that the problem may have resulted from the high traffic volume on the main road, combined with a high number of left-turning movements off the main road. Drivers at the stop sign need to look back over their shoulders at a sharp angle to watch the westbound traffic with which they are attempting to merge. The sight distance to the westbound traffic was excellent; however, the driver must move his or her head through a large angle when starting forward, to view a path directly ahead while moving out. The gap in westbound traffic that allows the driver to pull out onto the main highway also allows an eastbound driver to make a left turn onto the minor road. There is a large change in the line of sight from monitoring oncoming westbound traffic to looking ahead at the path about to be taken. This can result in drivers being startled by a left-turning vehicle coming toward them, leading the drivers to stop again, risking being rear-ended by the following driver. The following driver would have also seen the gap that the driver in front was prepared to take, would have started moving forward in anticipation, and would then be unprepared for the driver in front to stop suddenly.

Follow-Up Investigation

Given the uncertainty about the mechanism involved in the 9 of 12 accidents, an observational study is recommended so that the hypothesized mechanism can be verified. A statistical study might be used to determine the major road volume and merging volumes associated with this type of accident.

Accidents

The 12 accidents reported at this intersection over a 2-year period included the following:

- 9 attributable to the intersection, with all nine involving a two-vehicle, rear-end collision on the minor approach.
- 1 attributable to the curved approach.
- 1 other (concrete debris from another vehicle struck driver).

Site 26

This site consisted of the following:

- Three-legged intersection.
- Minor road at an angle.
- Major ADT of 9,000 vehicles per day.
- Minor ADT of 4,000 vehicles per day.
- Average accident rate of 2.13 accidents per million entering vehicles.

Police Reports

The police report summary showed 17 accidents at this intersection, two-thirds in daylight conditions, two-thirds on dry roads, and one-third on wet, snowy, or icy roads. Of the total, eight were coded as rear-end accidents. The predominant accident pattern (5) involved eastbound drivers stopped to turn left and being rear-ended by following drivers. Three rear-end accidents occurred as southbound vehicles pulled away from the stop sign, stopped, and were rear-ended by following vehicles. Three northbound drivers making left-turns were hit by drivers on the main road. Three accidents involved deer, and one, a blown tire.

Site Visit

The alignment for the minor road had been changed completely. At the original site, there was a right-turn lane created through lane marking on the original road, to enter a private road on the southbound side. On the original alignment, there was not adequate space between the end of the second lane and a guardrail to allow the second lane to be used as a bypass lane for drivers wanting to pass stopped left-turning vehicles. The minor road was angled back toward eastbound drivers. Eastbound drivers could not see the road surface of the minor road, making the slowing or stopping of vehicles to turn left less expected than might be otherwise. Sight distance from the minor road at the stop sign was poor, being about 8 s to the west and 10 s to the east. This likely accounts for the one-third of the accidents that involved vehicles entering the main road from the minor road.

Accidents

The 17 accidents reported at this intersection over a 2-year period included the following:

- 13 intersection crashes [5 rear-end on major, 4 involving vehicles entering from the major and the minor approaches, 3 rear-end accidents on the minor, and 1 other (drove over stop sign)].
- 3 deer.
- 1 other (blown tire).

Site 34

This site consisted of the following:

- Three-legged intersection.
- Major ADT of 1,400 vehicles per day.
- Minor ADT of 350 vehicles per day.
- Average accident rate of 9.81 crashes per million entering vehicles.

Police Reports

The police report summary showed 10 accidents at this intersection, 8 in daylight conditions and all on dry roads. The collision diagram drawn from the police reports showed that the predominant accident pattern (all accidents) involved westbound vehicles running off the road on a sharp curve at the intersection. Nine vehicles went off the right side of the curve; one vehicle went off the left side. Most of the accidents appeared to have happened during tourist season.

The police reports classified 7 of the 11 accidents as intersection related; however, they are possibly related to the curve and not to the intersection itself.

Photolog

The photo shows a sharp curve at the intersection with the minor road. A curve warning sign with a 25-mi/h (40-km/h) speed tab is also shown prior to the curve. Four chevron markers are shown along the outside of the curve.

Site Visit

The very sharp horizontal curve related to all of the accidents recorded at the intersection was out of character for the previous 16 km (10 mi) of roadway; the alignment was essentially straight, and was much sharper than curves encountered in the previous 48 km (30 mi), where the lowest signed speed on curves was 65 km/h (40 mi/h). One of the chevron markers had obviously been hit and was not well positioned with respect to the road path. The intersecting road created a gap in the chevron markers. However, even with this gap, a better job of outlining the curve could have been done. Traffic on the minor road appeared to be minimal.

Accidents

The 10 accidents reported at this intersection over a 2-year period included the following:

- 0 intersection crashes.
- 10 crashes related to the horizontal curve.

USEFULNESS OF SITE VISITS

From the police reports, photologs, and collision diagrams, a great deal of information was obtained with respect to the types of problems that might have been the basis for the accidents observed at the intersections.

Site visits yielded further insights, as indicated in the following.

> At site 34, the main problem was younger drivers running off the curve that goes into the intersection. This very sharp curve was out of character with the previous 16 km (10 mi) of roadway, and was much sharper than curves encountered in the previous 48 km (30 mi). Most of the accidents happened during tourist season, and the intersection was in a tourist region, suggesting a problem with drivers unfamiliar with the roadway.

FOLLOW-UP INVESTIGATIONS

The site visits raised a number of issues that would be useful for further investigations using a statistical approach. For example, at site 12, a bypass lane had been created through lane marking on the original road. There was a noticeable pattern of left-turning vehicles on the main road being rear-ended by following vehicles. A statistical analysis comparing three-legged intersections with various levels of through and left-turning traffic could be used to determine the thresholds at which full-width left-turn lanes should be implemented.

On many of the intersection approaches, there were sight distance limitations. The degree to which this would be likely to give rise to accidents would be related to the time taken to cross the intersection. That is, the difference between the time required to cross the intersection and the time during which oncoming traffic can be viewed represents the available safety margin. This time difference, in combination with measurements of main road volume and turning movements, is hypothesized to predict the risk of accidents related to intersection design.

It would be useful to establish the correlation between sight distance measured on plans and sight distance measured at the site. The underlying question is, How do plans deal with sight distance changes due to shrubbery and seasonal changes? This would indicate how necessary it is to go to the site to obtain such information.

The site visits also raised issues that could be further investigated using behavioral studies. These include the start, stop, and rear-end sequences that occurred at sites 17 and 26. Both sites involved a minor road at an angle with the major road. It may be that these accidents occur because there is a large angle between the line of sight for merging traffic and the one for the path about to be taken. With such a large angle, the driver loses peripheral vision information. Then, when the driver turns back to start forward, the driver may be surprised to see a vehicle coming from the main road, and then stops suddenly, giving the following driver insufficient warning to stop also.

Behavioral studies use eye movement recording equipment to assess the visual search behavior of drivers as they approach intersections. This would be very valuable in identifying the areas where drivers are potentially vulnerable to distractions, such as billboards adjacent to intersections.

POTENTIAL CONCERNS

Based on the analysis of accidents at rural intersections, the following designs should be of concern to geometric designers.

Bypass lanes for left-turning traffic. Once left-turning traffic and through traffic reach certain thresholds (established through statistical analysis), a bypass lane is inadequate and likely to lead to rear-end collisions.

Bypass lanes on downgrades. Where drivers must stop in the through lane to turn left, a downgrade can contribute to rear-end accidents, especially under wet or icy conditions.

Crest vertical curves on minor road approaches. Crest vertical curves, on a minor road approach to an intersection should not be combined with poor sight distance for traffic turning left or crossing the main road, especially where volume on the major road is high. This situation can be problematic when the road surface condition is degraded, which can result in drivers that are pulling out from the minor road having insufficient time to cross the intersection.

Sharp curves near freeway exits. Where traffic exits a freeway and is still traveling at higher speeds than on two-lane highways, the first curves encountered should not be notably sharper than those encountered on the freeway.

Unusually sharp curves in a section of roadway. Curves that are noticeably sharper than any encountered in the previous 8 km (5 mi) of roadway should be avoided.

Angled minor-road approaches, especially combined with poor sight distance. A sharp angle between the major and minor road can result in a driver on the minor road losing peripheral information and being surprised by a left-turning or through vehicle on the major road just as he or she is about to merge onto the major road.

RECOMMENDED APPROACH

Based on the accident analyses at the sites, the following approach is recommended.

Accident Summaries and Police Reports

Accident summaries should be reviewed to obtain information about overall accident characteristics, such as time of day, road conditions, and light conditions, among other factors. Police reports should be reviewed to obtain information about the initiating event and the collision consequences. Speed limit information, intersection layout, and lighting information can also be obtained. For each collision, driver age, time of day, roadway and lighting conditions can be obtained.

Collision Diagrams

Collision diagrams should be drawn with an accurate geometric layout. Collisions should be grouped in terms of initiating events. This allows designers to focus on the problem, as opposed to the consequences of the problem. It is helpful to indicate driver age, light/dark, dry/wet/ice, time of day, and date for each accident.

Collision diagrams should include all accidents, to gain an overall picture. However, some accidents do not have initiating events that are amenable to geometric design changes. Examples are deer accidents, crashes in which a driver fell asleep while traveling through an intersection, or crashes related solely to vehicle defects. These accidents are of less interest in the first stage of analysis, but they should be considered when analyzing the consequences of the accident. A second collision diagram could be drawn showing the paths and resting places of vehicles after a collision. Such a diagram can indicate where guardrails might be placed, where obstacles might be removed, or where design changes might be made if the initiating problem cannot be fixed. The only option may be to improve the roadway so that the consequences of the accidents are less severe. Here, a collision diagram that considers consequences may be more useful.

Site Visits

During an intersection site visit, the driver's view on each approach should be examined to determine:

- Time during which crossing traffic is potentially visible both from the minor and the major road (i.e., sight distances should be converted to times available).
- Time during which traffic ahead stopped in or before the intersection can be viewed.
- Time needed to cross the intersection from a full stop, straight through, time needed to cross the intersection while turning left or right, and finally, time needed to get up to traffic speed.
- Difficulty of obtaining information about intersecting traffic, due to the angle through which the head must be moved to assess traffic on a major road.
- Visual distractions at critical points when the driver's attention should be focused elsewhere (e.g., a billboard to the right when the driver is approaching a three-legged intersection on the left, with potential stopping ahead of left-turning traffic, or a railway crossing ahead when the driver should be focused on the intersection immediately ahead).

Times recorded for the first item should be marked on the collision diagram.

In addition, the area around the site should be examined to determine:

- Operations in the vicinity that attract certain classes of drivers (e.g., high schools and teenage drivers, taverns and drunk drivers, tourist areas and a high percentage of unfamiliar drivers).
- Characteristics of the intersection layout, e.g., if there is a number of "ran stop sign" accidents, the roadway layout may not be giving the driver a sufficiently strong cue that there is a stop ahead. A limited view of the intersection approach and/or a limited view of the road surface of the intersecting road can contribute to a low expectation of a need to stop.

- Potential traffic conflicts due to parking lots and/or driveways near the intersection.

- Characteristics of the road prior to the intersection, e.g., a long distance since the last required stop, or road markings, signing, or character noticeably different from the previous 8 to 16 km (5 to 10 mi) of roadway can surprise a driver and lead to errors.

A video record of the site visit is useful for later analysis. This record should include 15 to 20 s of the approach to the intersection on each leg. At stop signs, a slow pan to the right and to the left should be recorded, each pan lasting around 5 s. The video should be date and time stamped. The video should be shot by someone other than the driver, who can view what is being recorded as it is being recorded. Care should be taken that if a battery connection is being used, the connection is maintained as the vehicle hits bumps on the road.

At the beginning of the filming of an approach, the driver should note the site number, the direction of the approach, and the number of accidents experienced by vehicles using that approach. As the driver continues on the approach, he or she should comment on the adequacy of the sight distance if the approach is on a through road, and they should also note the critical signs and lane markings. This verbal commentary is important because not all signs, signals, and markings are as visible on the video as they are to the human eye. On the minor road approach, comments on the sight distance can be made as the camera is panned to the left and the right. These pans should include oncoming traffic, if possible.

Follow-Up Investigations

Analyses of specific sites can lead to the identification of issues that should be examined using a statistical approach. For example, these investigations showed that left-turn bypass lanes are associated with rear-end accidents initiated by stopped left-turning vehicles on the major road. Through statistical analyses, a threshold for turning movements and major and minor road volumes could be established, at which left-turn lanes should be implemented.

Analyses of specific sites can also lead to the identification of issues that should be examined using a behavioral approach. At site 17, a hypothesis was developed that would explain the large number of accidents involving vehicles rear-ended at the stop sign. Such a hypothesis could be validated by video observations at the intersection.

At site 12, it was hypothesized that drivers were distracted by a billboard just at the moment they should have been attending to left-turning traffic stopping ahead. Here, recording driver eye movements as they approached the intersection and comparing them with approaches to similar intersections where there are no distractions would help determine if such billboard placement inappropriately adds to the visual demand at a critical point.

APPENDIX C. FORENSIC ENGINEERING INVESTIGATION: SELECTED RURAL-INTERSECTION SITES

To arrive at an explanation of why accidents are occurring at a specific location, the accident data should be studied in light of the stages through which an accident proceeds. An accident has three major stages:

(1) Perception — the time required to identify a problem.

(2) Reaction — the time required to decide what to do.

(3) Avoidance — the action taken by the driver.

Influencing these stages are the following factors:

- Human Factors: Driver expectancy, age, experience, physical condition, familiarity with area, preoccupation/distraction.
- Road Factors: Alignment, sight distance, surface condition, signing, striping, lighting, weather.
- Vehicle Factors: Type, size, condition, equipment, weight/stability/center of gravity.

The predisposing factor is speed. Speed determines the time available to complete the three stages leading to the accident (determined from the available sight distance) and also contributes to the severity of injuries in the accident.

METHODOLOGY

The methodology for the forensic investigation should include the following steps:

- Review the accident reports and diagram the accidents. This will indicate the predominate accident type, direction of travel that needs to be reviewed, any trends or conditions that may be occurring, drivers' ages, time of accident, vehicle types, and extenuating circumstances. If the officer took photographs at the accident scene, this will be indicated on the accident report.
- Gather any available data pertaining to the accident location. If available, highway plans with profile sheets, aerial photographs, traffic volume data, and turning-movement counts for intersections would all be useful. Sometimes, there are newspaper articles that provide information on specific accidents, along with photographs of the vehicles.

- Field review the accident site. Ideally, this would be done at the time of the accident. The next best time would be under the same conditions as when the accident occurred (e.g., construction, school events, detour).

- Collect the data pertaining to the highway. This step includes the following actions:

  — Measure the available sight distance (note obstructions).
  — Consider the geometry (grades and curves).
  — Check the road surface condition, shoulders, and ditches (potholes, cracks, edge drop-offs, friction factors).
  — Check signing (age, size, location, spacing, height).
  — Note speed limit or advisory signing in the area.
  — Look at development and land use in the area (this will give clues on type of highway user).
  — Look for evidence of other accidents at the location (skid marks, debris, gouge marks in roads or slopes, broken guardrails, down signs, trees missing bark).

- Gather the appropriate data. The data gathered can be tailored to fit the direction of travel or the type of accident that appears predominately at the location being studied. Observation of traffic through the intersection may also give insights to driver behavior at the time of the accident. This could lend support to the contributing factors considered as the cause of the accident problem, or it could reveal another possibility. Possible actions also include the following:

  — Radar checks of speed in the area may be useful.
  — Interviews with people or businesses in the area can sometimes provide insights into the accident or perceived problem.
  — A review of the car damage can provide information on vehicle speed, behavior after the collision, and position at the time of the accident.
  — A review of medical reports on injuries sustained can provide information concerning who was driving and whether seatbelts were used.

BMI SITE #12 REPORT

Accident Data: **Intersection Accident Rate = 0.67**

Predominant Type — Rear-end accidents involving left-turning vehicles (10/15), northbound approach.
Accident Conditions — Daylight and dry roadway.
Unusual Factors — 8 accidents between noon and 3 p.m. (2 accidents involved deer and 1 was driveway-related).

Highway Data:

Road Class	U.S. Highway	CSAH
No. of Through Lanes	2	3
Auxiliary Lanes	Bypass - NB; Rt. Turn - SB	
Alignment	Straight	
Grade to Intersection	—	Downhill to Intersection
Speed Limit	90 km/h (55 mi/h)	
Speed Advisories		
Signing	Junction Sign, Arrow	
Sight Distance	NB - 300+ m, SB - 300+ m (1000+ ft)	
Traffic Volumes	23,835	2,559

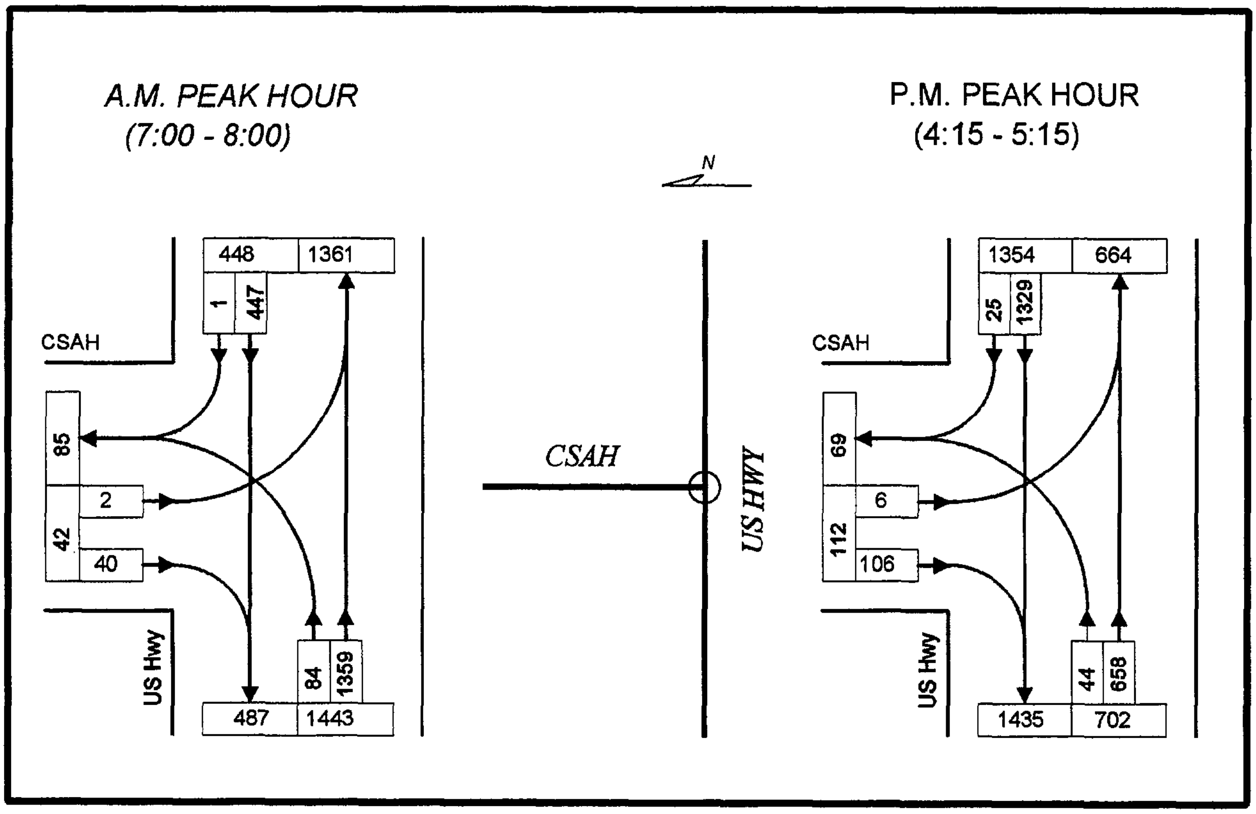
Comments:

— T-intersection.
— Skid mark evidence in the taper area to bypass lane.
— A large number of semi-trucks were observed in the traffic volume.
— Luminaire on east side of intersection.
— Billboard for "Lions Tap Tavern" across from CSAH.
— Guardrail runs the length of bypass lane; ~ 0.3- to 0.6-m (1- to 2-ft) shoulder in bypass area.
— Southbound vehicles arrive in platoons.
— Four-lane highway and signals approximately 3 km (2 mi) north.

Analysis/Opinion:

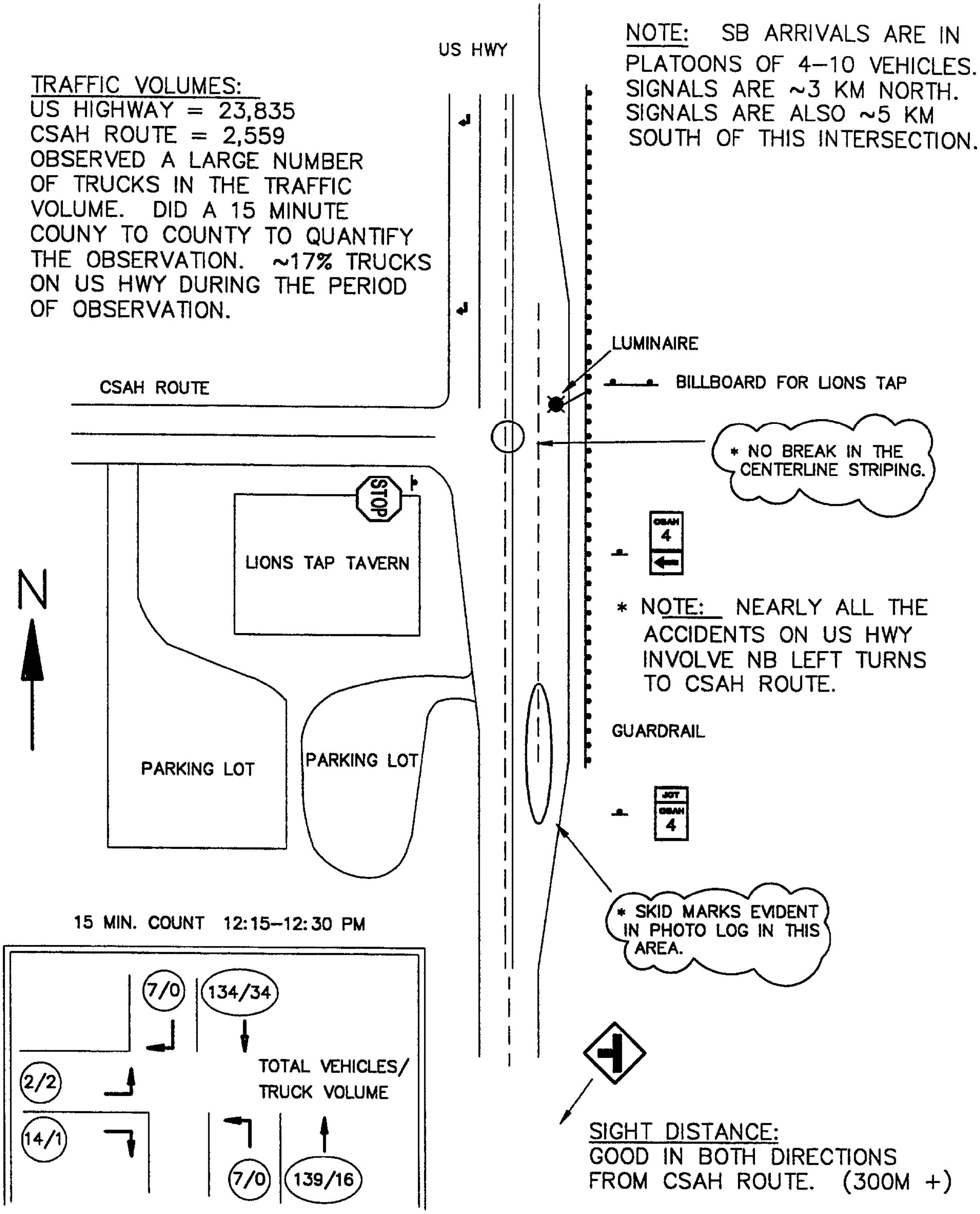
- The accident rate is relatively low for this intersection.
- This area has very high volumes for a two-lane highway; a four-lane highway would generally be expected for these volumes.
- Since this is a T-intersection, a separate left-turn lane would be a better condition than a bypass lane for these vehicles. Speculation: the high truck volume and limited road width for a shoulder in the bypass area may be the reasons this treatment was used. The left-turn activity may also be low.

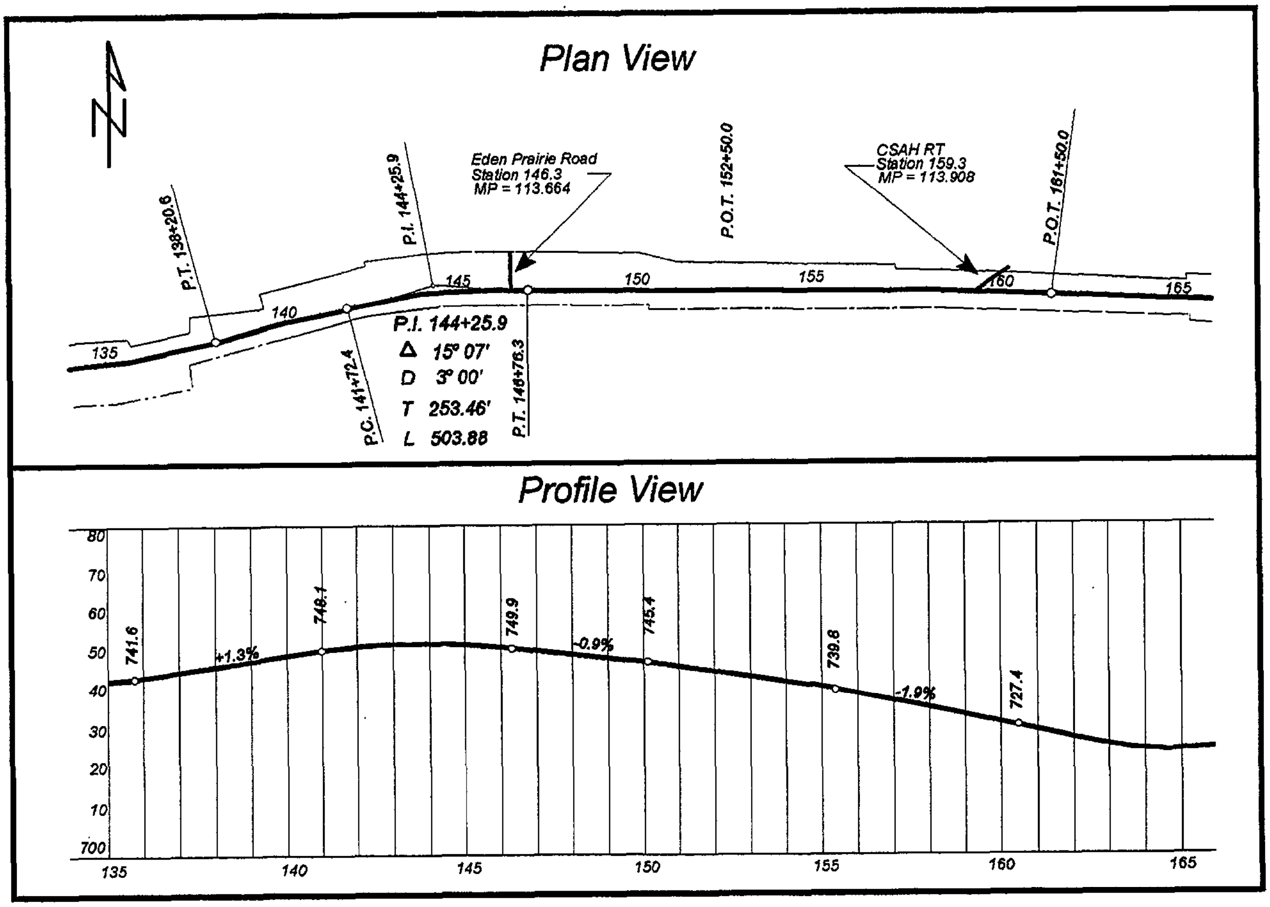
Peak Hour Turning Movements:



SITE #12

(DATE OF FIELD INVESTIGATION: 10-28-96)





Plan View
P.T. 138+20.6
P.I. 144+25.9
Eden Prairie Road
Station 146.3
MP = 113.664
P.O.T. 152+50.0
CSAH RT
Station 159.3
MP = 113.908
P.O.T. 161+50.0
135
140
145
150
155
160
165
P.I. 144+25.9
Δ 15° 07'
D 3° 00'
T 253.46'
L 503.88
P.C. 141+72.4
P.T. 146+76.3
Profile View
80
70
60
50
40
30
20
10
700
741.6
+1.3%
749.1
749.9
-0.9%
745.4
739.8
-1.9%
727.4
135
140
145
150
155
160
165

Collision Diagram

BMI # 12

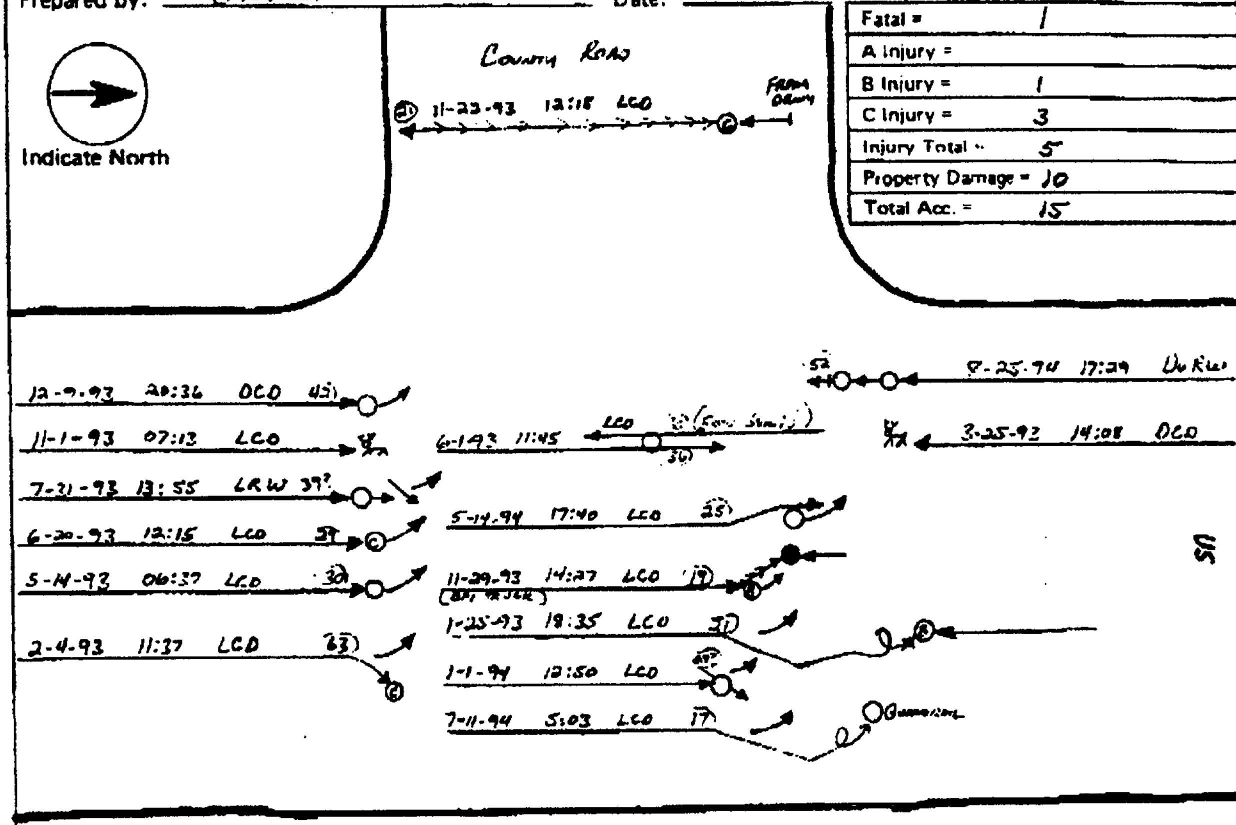
Location:

Time Period: 1993 + 1994

Prepared by: Gary Shannon Date: 10-96

No. of Accidents	
Fatal =	1
A Injury =	
B Injury =	1
C Injury =	3
Injury Total =	5
Property Damage =	10
Total Acc. =	15

Indicate North



Legend	
→	Motor Vehicle Moving Ahead
⟵⟶	Motor Vehicle Backing Up
~→	Motor Vehicle Out of Control
	Pedestrian
	Bicycle/Moped
	Motorcycle
□	Fixed Object
●	Fatal Acc.
Ⓐ	A Injury Acc.
Ⓑ	B Injury Acc.
Ⓒ	C Injury Acc.
○	Property Damage Acc.
→○→	Rear End Property Damage
→Ⓑ	Right Angle B Injury

Light:
L = Daylight (1)
DN = Dawn (2)
Du = Dusk (3)
D = Dark (4, 5 or 6)
X = Unknown

Weather:
C = Clear or Cloudy (1 or 2)
R = Rain (3)
S = Snow or Sleet (4 or 5)
X = Other or Unknown

Surface:
D – Dry (1)
W = Wet (2)
S – Snow or Ice (3 or 4)
X = Other or Unknown

Example of Bicycle/Motor Vehicle Accident:

Injury Type 6-4-78 Du-C-D

Date + Time Light – Weather – Surface

BMI SITE #17 REPORT

Accident Data: **Intersection Accident Rate = 1.49**

Predominant Type — Rear-end collisions on CSAH (9/11), westbound approach.
Accident Conditions — Daylight, dry roadway.
Unusual Factors — All the drivers at fault were in their 20's. The accidents occurred mainly between 4 p.m. and 6:30 p.m.

Highway Data:

Road Class	U.S. Highway	CSAH
No. of Through Lanes	2	2
Auxiliary Lanes	Bypass - EB	
Alignment	Curve	Very skewed: Aligns with EB U.S. Hwy
Grade to Intersection	Downhill to East	Level
Speed Limit	80 km/h (50 mi/h)	50 km/h (30 mi/h)
Speed Advisories		
Signing	EB only Junction, Arrow	
Sight Distance	EB - 300+ m (1000+ ft), WB - 245+ m (800+ ft)	
Traffic Volumes	10,171	3,700

Comments:

— T-intersection.
— Railroad crossing on CSAH ~ 30 m (1000 ft) from U.S. highway.
— Luminaire in southeast quadrant of intersection.
— Unusual/nonstandard signing for intersection. (Straight-ahead arrow for exit move to CSAH; diagonal arrows for U.S. highway through-traffic; "Signal Your Turn" sign.)

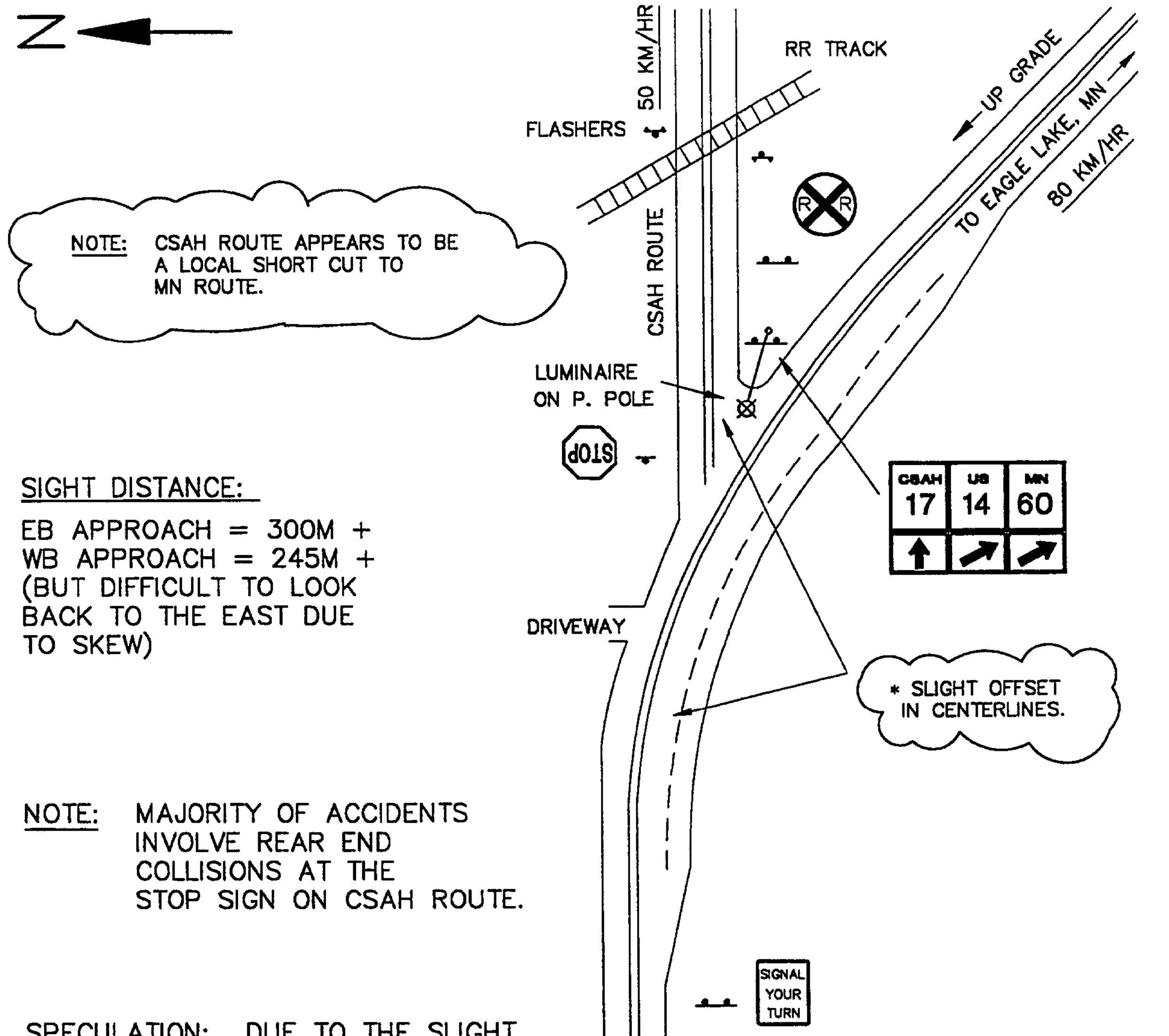
Analysis/Opinion:

— Since sight distance is good and the predominant accidents are occurring on CSAH at the stop sign, the assumption has to be made that the skew of CSAH to U.S. highway westbound is the proximate geometric cause. The listed contributing human factors are: (1) driver distraction/inattention (looking to the east down U.S. highway, not paying attention to the vehicles in front of them), and (2) improper driver behavior — following too close and/or starting improperly.

The use of unusual signing ("Signal Your Turn") on eastbound U.S. highway indicates the straight-ahead exit to CSAH from U.S. highway has created some concern at this location. This signing was probably placed in an attempt to encourage the eastbound traffic to signal their intent to turn.

SITE #17

(DATE OF FIELD INVESTIGATION: 10-28-96)



NOTE: CSAH ROUTE APPEARS TO BE A LOCAL SHORT CUT TO MN ROUTE.

SIGHT DISTANCE:

EB APPROACH = 300M +
WB APPROACH = 245M +
(BUT DIFFICULT TO LOOK BACK TO THE EAST DUE TO SKEW)

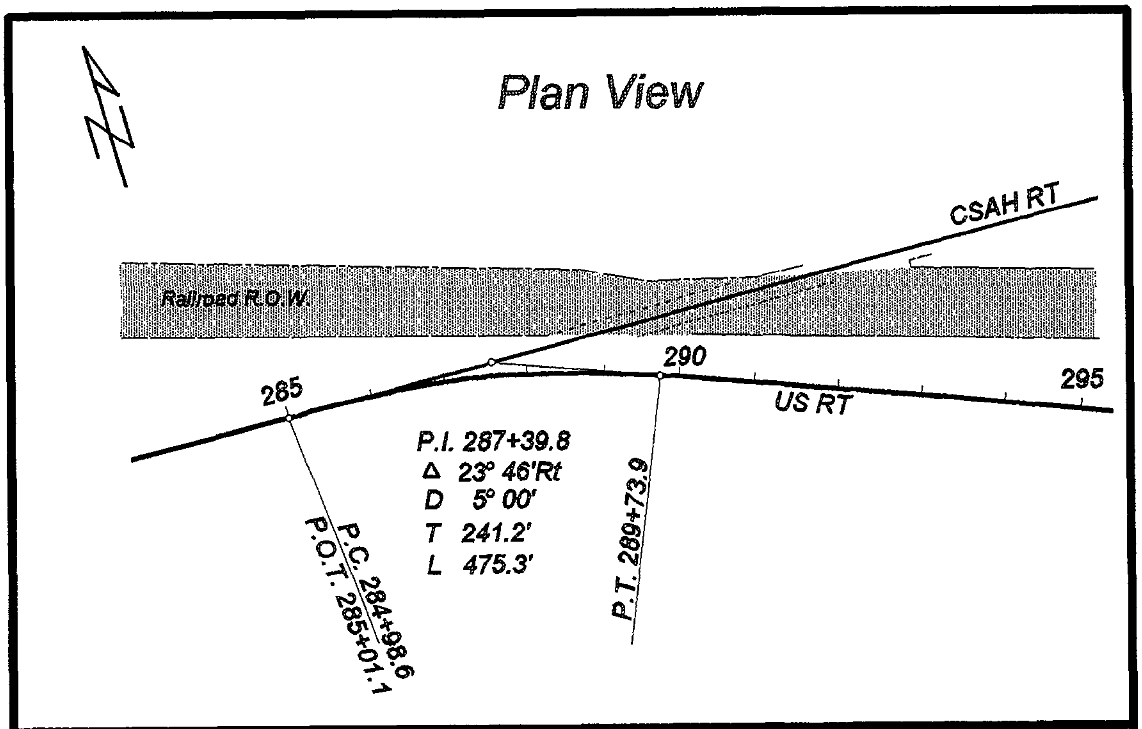
NOTE: MAJORITY OF ACCIDENTS INVOLVE REAR END COLLISIONS AT THE STOP SIGN ON CSAH ROUTE.

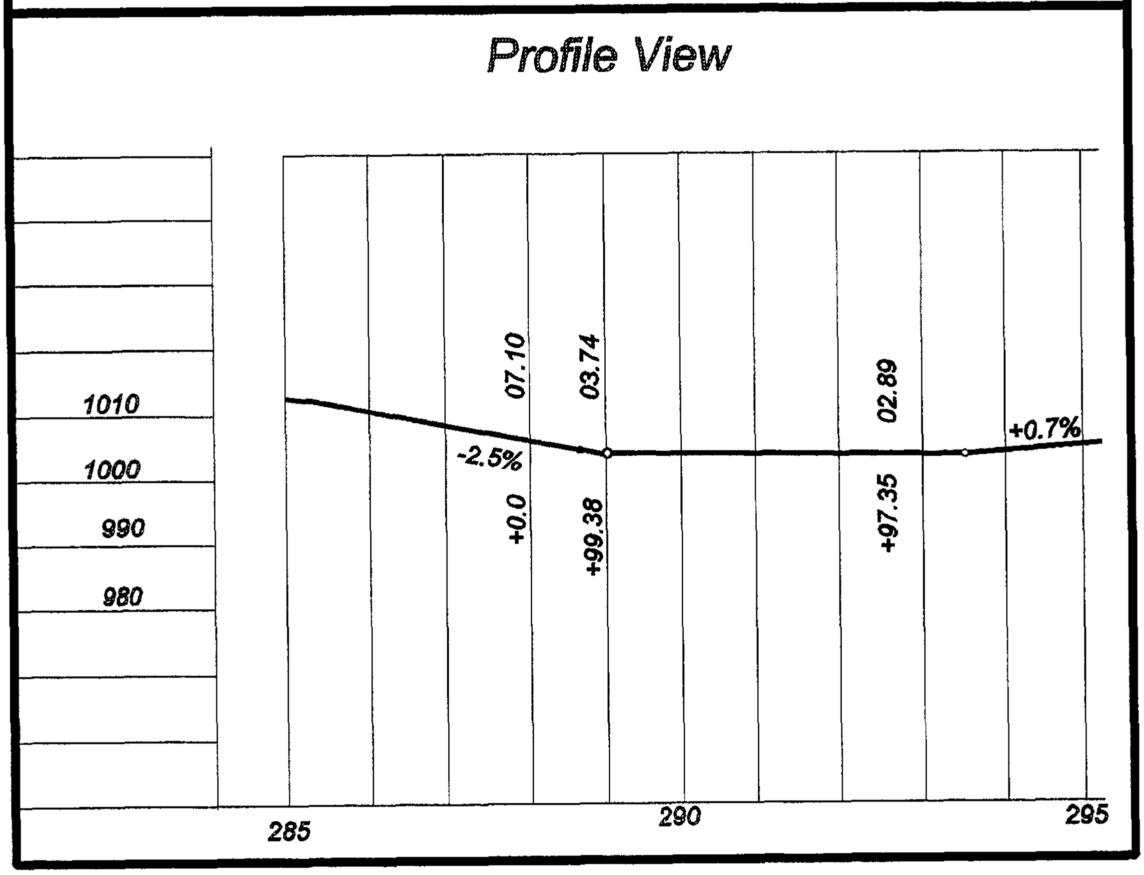
SPECULATION: DUE TO THE SLIGHT OFFSET IN US HWY/CSAH ROUTE ALIGNMENTS, AN EB LEFT TURN FROM US HWY MAY STARTLE A DRIVER ON CSAH ROUTE. THE DRIVER MAY HAVE BEEN LOOKING BACK OVER HIS/HER LEFT SHOULDER, PERCEIVED A GAP AND MADE A DECISION TO GO. THEN, THE DRIVER MAY HAVE ENCOUNTERED A VEHICLE TURNING FROM WB US HWY INTO HIS/HER PATH AND STOPPED ABRUPTLY, WHICH RESULTED IN A REAR-END CRASH.

NOTE: NO JUNCTION SIGNING WEST BOUND ON US HWY.

TRAFFIC VOLUMES:

US HIGHWAY = 10,171
CSAH ROUTE = UNKNOWN


Plan View
CSAH RT
Railroad R.O.W.
290
285
295
US RT
P.I. 287+39.8
Δ 23° 46'Rt
D 5° 00'
T 241.2'
L 475.3'
P.C. 284+98.6
P.O.T. 285+01.1
P.T. 289+73.9


Profile View
1010
1000
990
980
07.10
03.74
02.89
-2.5%
+0.7%
+0.0
+99.38
+97.35
285
290
295

Collision Diagram

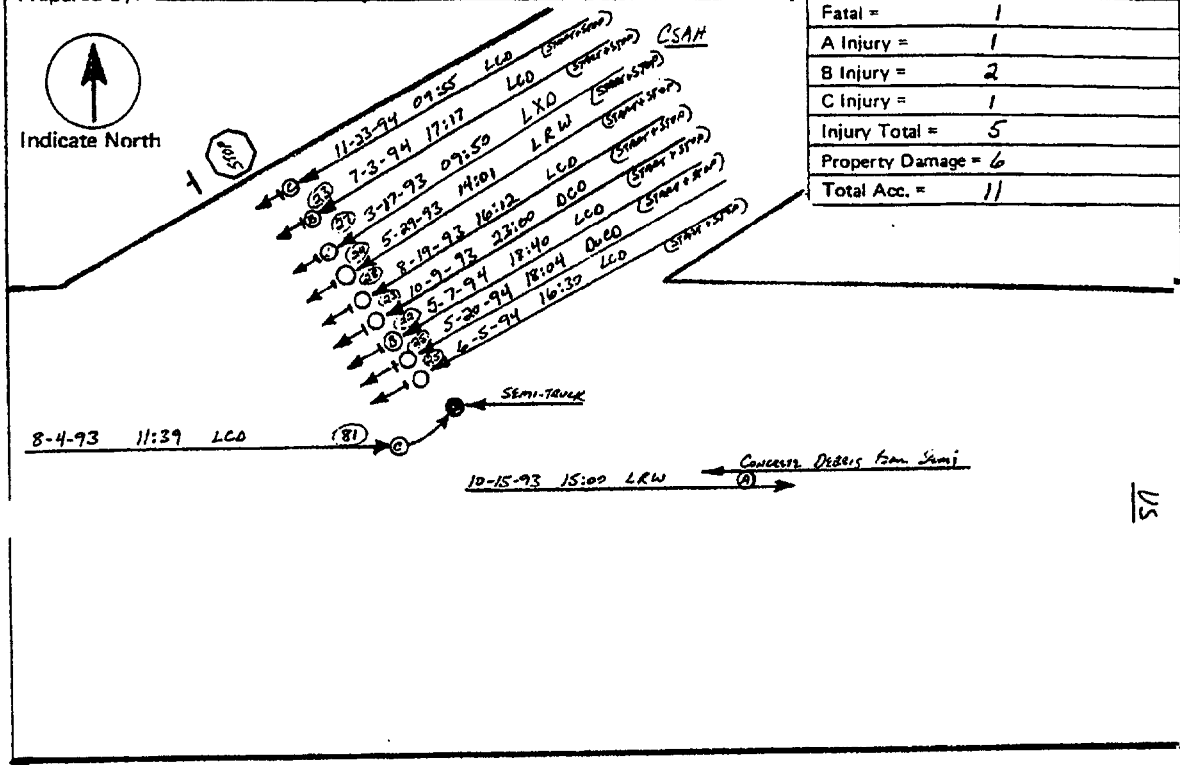
BMI # 17

Location:

Time Period: 1993 + 1994

Prepared by: Gary Shannon   Date: 10-96

No. of Accidents	
Fatal =	1
A Injury =	1
B Injury =	2
C Injury =	1
Injury Total =	5
Property Damage =	6
Total Acc. =	11



- Motor Vehicle Moving Ahead
- Motor Vehicle Backing Up
- Motor Vehicle Out of Control
- Pedestrian
- Bicycle/Moped
- Motorcycle
- Fixed Object
- Fatal Acc.
- A Injury Acc.
- B Injury Acc.
- C Injury Acc.
- Property Damage Acc.
- Rear End Property Damage
- Right Angle B Injury

Light:
L = Daylight (1)
DN = Dawn (2)
Du = Dusk (3)
D = Dark (4, 5 or 6)
X = Unknown

Weather:
C = Clear or Cloudy (1 or 2)
R = Rain (3)
S = Snow or Sleet (4 or 5)
X = Other or Unknown

Surface:
D = Dry (1)
W = Wet (2)
S = Snow or Ice (3 or 4)
X = Other or Unknown

Example of Bicycle/Motor Vehicle Accident:

Injury Type   6-4-78   Du-C-D

Date = Time   Light — Weather — Surface

BMI SITE #26 REPORT

Intersection has been reconstructed at a new location.

Old Location Accident Data: **Intersection Accident Rate = 1.75**

Predominant Type — Rear-end collisions with eastbound left-turn vehicles (5/11), eastbound approach.
Accident Conditions — Daylight, dry roadway.
Unusual Factors — 3 accidents involved deer.

Old Location Highway Data:

Road Class	Minnesota Highway (MN)	County Road (CR)
No. of Through Lanes	2	2
Auxiliary Lanes	Right Turns	
Alignment	Curves North and South	Skewed and Curved
Grade to Intersection	~3-4% Downhill to East	Downhill to South
Speed Limit	90 km/h (55 mi/h)	
Speed Advisories		
Signing		
Sight Distance	WB - 245+ m (800+ ft), EB - 220± m (700± ft)	
Traffic Volumes	9,016	3,791

Comments:

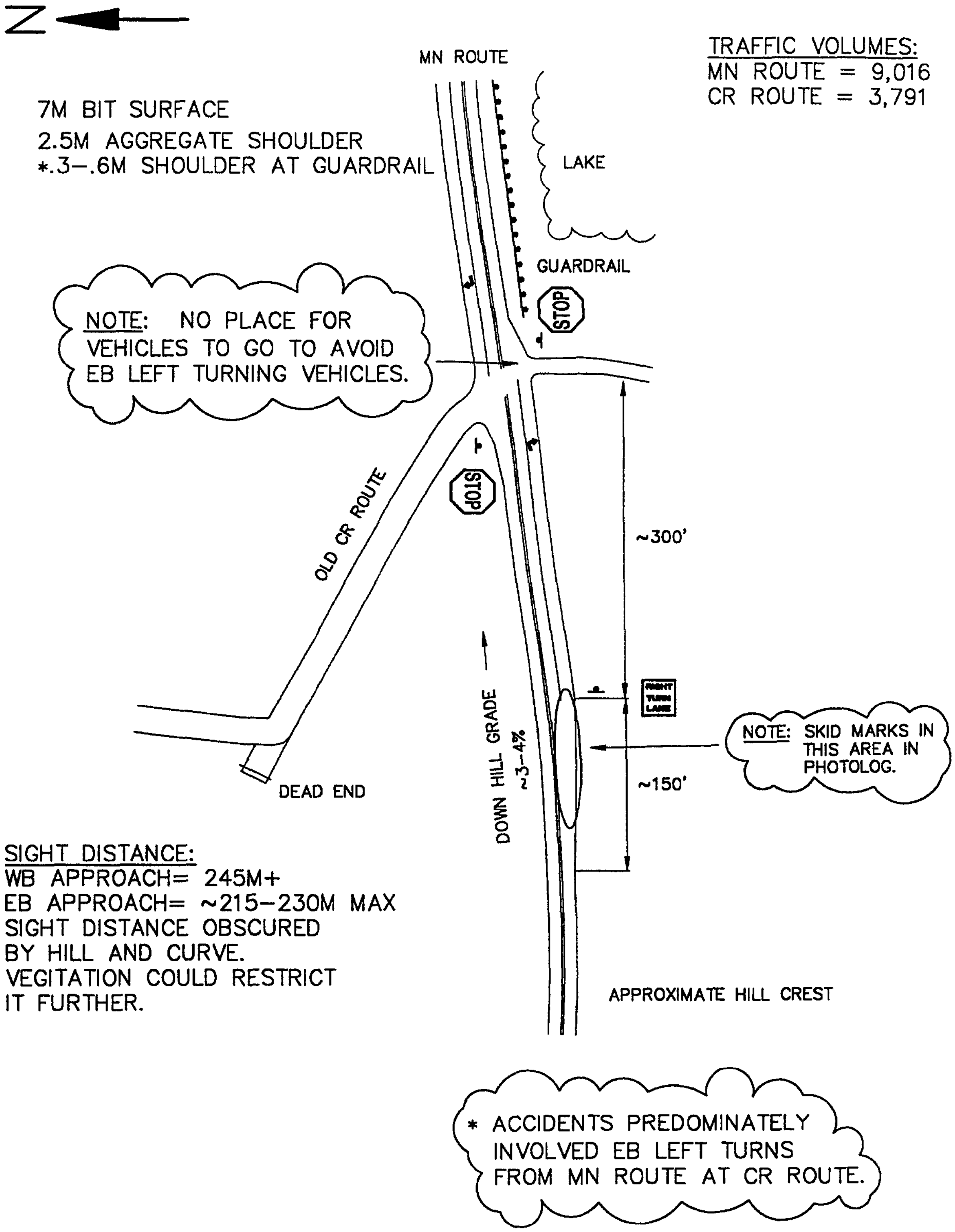
- Township Road offset across from CR on MN .
- Skid marks on MN at start of eastbound right-turn lane.
- Shoulders are 2.5-m- (8-ft-) wide aggregate, except at CR where they narrow to 0.3 to 0.6 m (1 to 2 ft) by the guardrail.

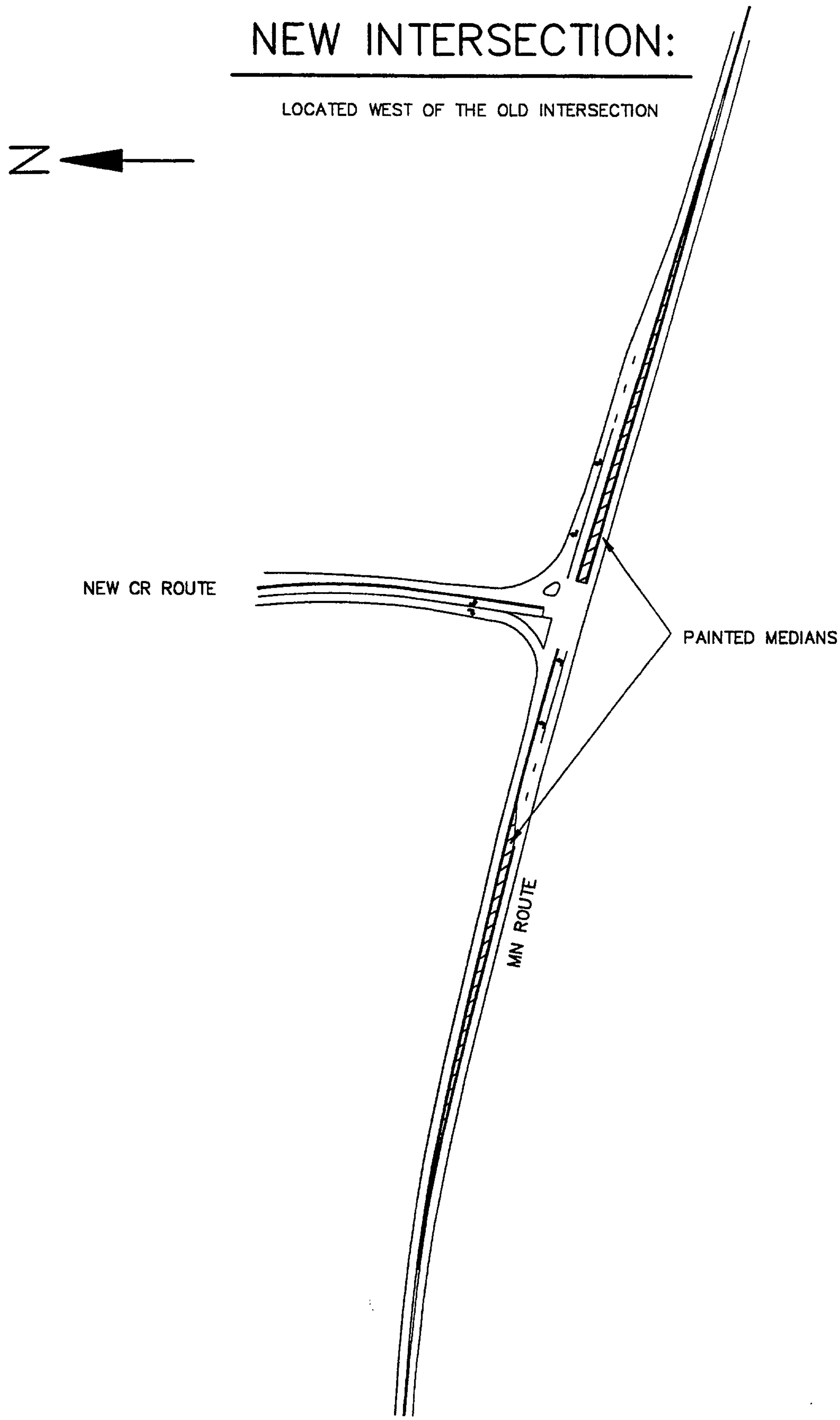
Analysis/Opinion:

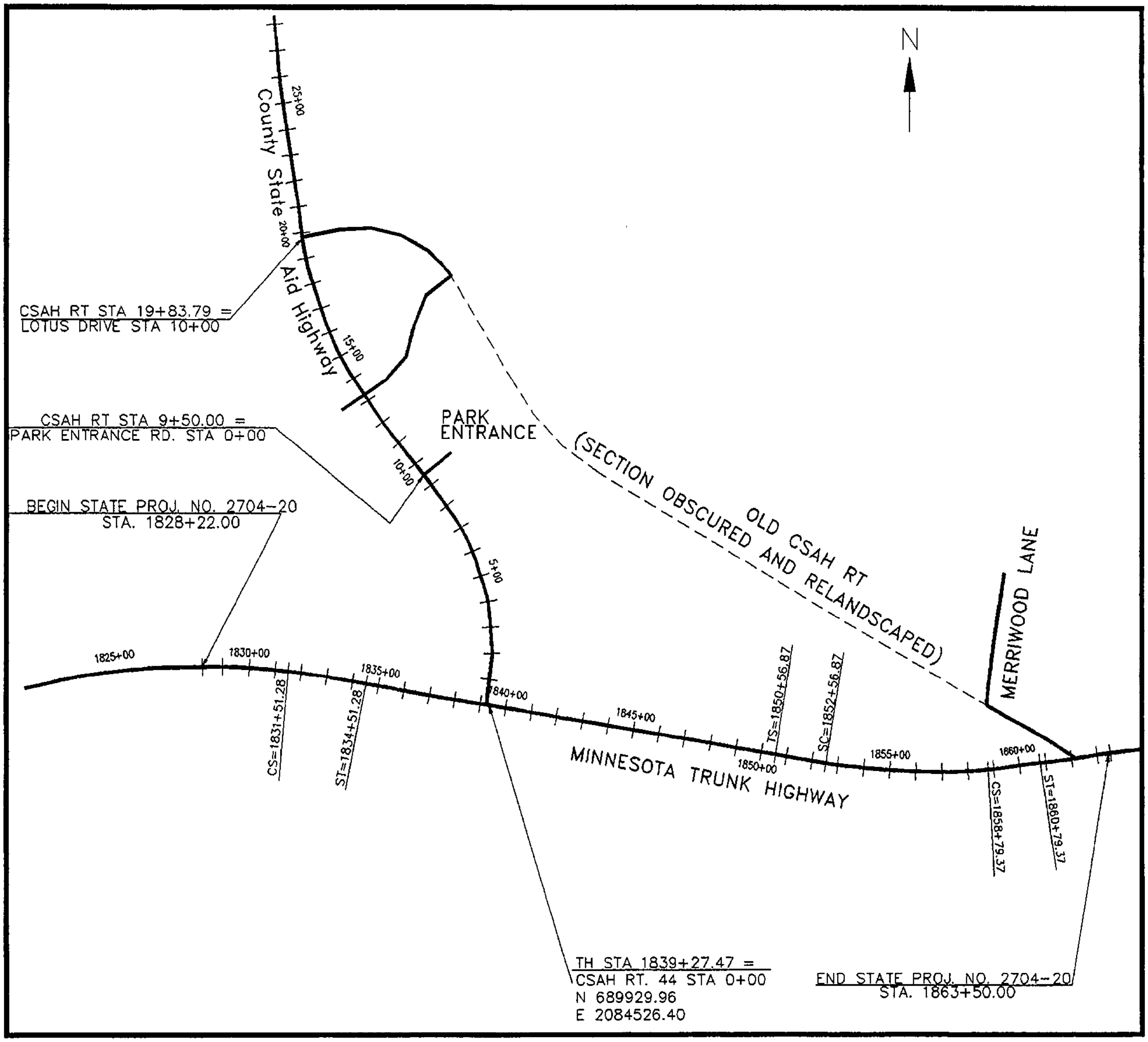
- Traffic volumes are high for a two-lane highway.
- This intersection has neither a left-turn lane nor a bypass lane, requiring through traffic to stop for any left-turn movement.
- It is likely that several vehicles will be required to stop behind the turning vehicles, and following vehicles may be surprised or confused by this. The possible collision point (last vehicle in line) will also be moved up the hill nearer the hill crest.
- The crest vertical curve restricts sight distance for eastbound MN traffic, allowing approximately 8.5 s for perception, reaction, and avoidance.
- The horizontal curve for eastbound MN complicates the evaluation of traffic conditions at the intersection with CR, and increases the difficulty to perceive that "stopping" is the only avoidance reaction available. (When the "Right-Turn Lane" sign is legible, the vehicle will be approximately 130 m (425 ft) from the intersection.)

SITE #26

(DATE OF FIELD INVESTIGATION: 10-30-96)




NEW INTERSECTION:
LOCATED WEST OF THE OLD INTERSECTION
N
NEW CR ROUTE
PAINTED MEDIANS
MN ROUTE


N
County State Aid Highway
CSAH RT STA 19+83.79 =
LOTUS DRIVE STA 10+00
CSAH RT STA 9+50.00 =
PARK ENTRANCE RD. STA 0+00
PARK
ENTRANCE
BEGIN STATE PROJ. NO. 2704-20
STA. 1828+22.00
(SECTION OBSCURED AND RELANDSCAPED)
OLD CSAH RT
MERRIWOOD LANE
MINNESOTA TRUNK HIGHWAY
CS=1831+51.28
ST=1834+51.28
TS=1850+56.87
SC=1852+56.87
CS=1858+79.37
ST=1860+79.37
TH STA 1839+27.47 =
CSAH RT. 44 STA 0+00
N 689929.96
E 2084526.40
END STATE PROJ. NO. 2704-20
STA. 1863+50.00

Collision Diagram

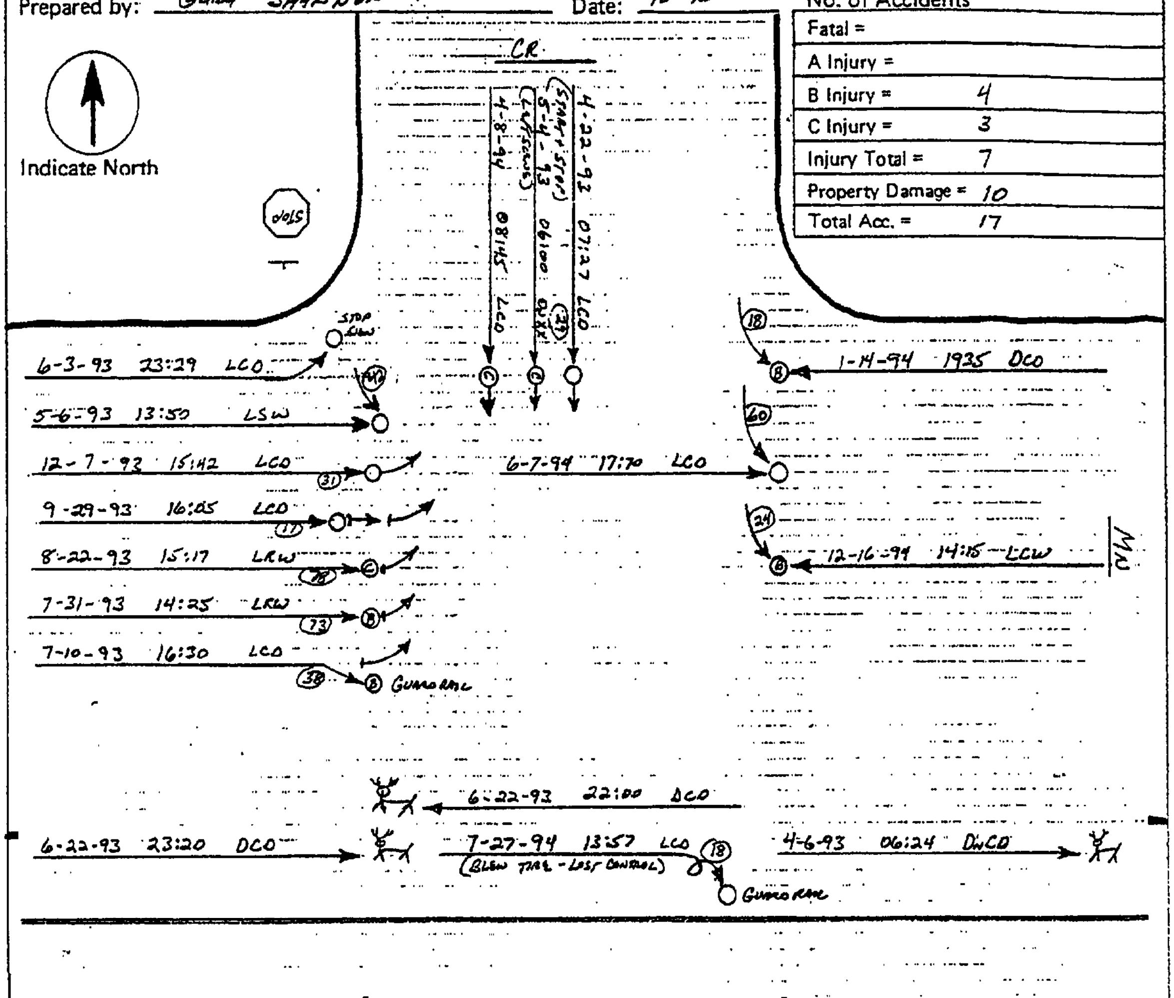
BMI # 26

Location:

Time Period: 1993 + 1994

Prepared by: Gary Shannon Date: 10-96

No. of Accidents	
Fatal =	
A Injury =	
B Injury =	4
C Injury =	3
Injury Total =	7
Property Damage =	10
Total Acc. =	17



Symbol	Meaning
⟶	Motor Vehicle Moving Ahead
	Motor Vehicle Backing Up
	Motor Vehicle Out of Control
	Pedestrian
	Bicycle/Moped
	Motorcycle
□	Fixed Object
●	Fatal Acc.
Ⓐ	A Injury Acc.
Ⓑ	B Injury Acc.
Ⓒ	C Injury Acc.
○	Property Damage Acc.
	Rear End Property Damage
	Right Angle B Injury

Light:	Weather:	Surface:
L = Daylight (1)	C = Clear or Cloudy (1 or 2)	D = Dry (1)
DN = Dawn (2)	R = Rain (3)	W = Wet (2)
Du = Dusk (3)	S = Snow or Sleet (4 or 5)	S = Snow or Ice (3 or 4)
D = Dark (4, 5 or 6)	X = Other or Unknown	X = Other or Unknown
X = Unknown		

Example of Bicycle/Motor Vehicle Accident:

Injury Type 6-4-78 Du-C-D

Date = Time Light – Weather – Surface

BMI SITE #34 REPORT

Accident Data: **Intersection Accident Rate = 9.81**

Predominant Type — Run-off-road on right side (9/10), northbound approach.
Accident Conditions — Daylight, dry roadway.
Unusual Factors — 8 accidents involved drivers under 23 years of age, all during the summer months.

Highway Data:

Road Class	Minnesota Highway (MN)	County Road (CR)
No. of Through Lanes	2	2
Auxiliary Lanes	NB - Right-Turn Lane	
Alignment	90° Curve	Aligns with WB MN
Grade to Intersection	Fairly Level	Level
Speed Limit	90 km/h (55 mi/h)	
Speed Advisories	40 km/h (25 mi/h) (turn)	
Signing	Junction, Arrow	
Sight Distance		
Traffic Volumes	1,363	347

Comments:

- T-intersection.
- The curve is approximately 135 m (450 ft) long with 90-m (300-ft) tangents.
- The chevrons are mounted back-to-back on posts.
- The northbound "Turn" sign is located approximately 105 m (350 ft) south of the curve P.C.

Analysis/Opinion:

- The contributing geometric problem is the 90° curve with a high degree of curvature.
- The listed contributing factors were: speed (9), driver inattention/distraction (4), physical impairment of the driver (3).

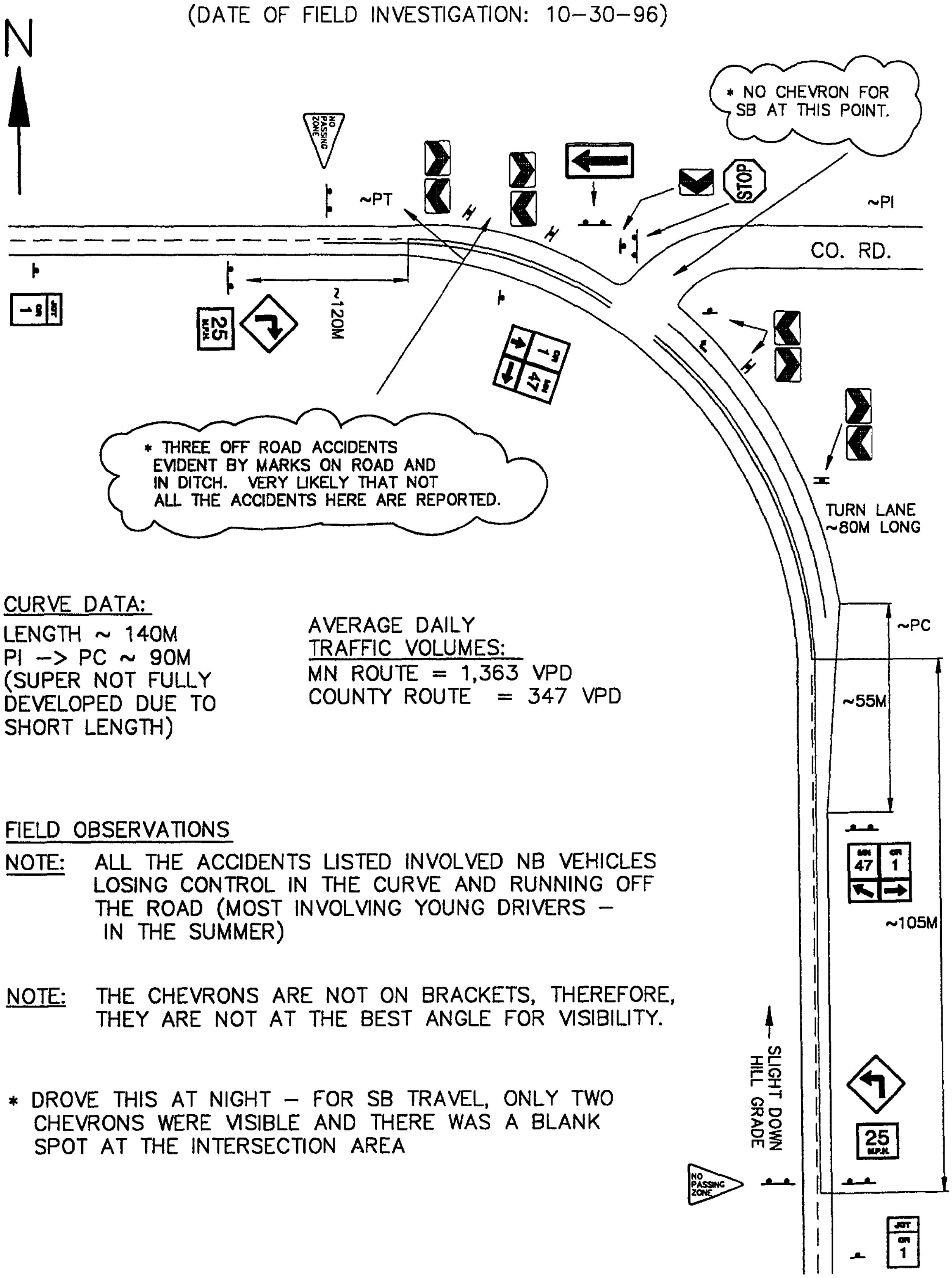
— Advance warning signs for the curve are in place for both directions. Signing installations are similar for both directions, yet there are no reported accidents for southbound vehicles.

Note: 1. The Minnesota MUTCD indicates that the location of advance warning signs should be between 145 m (475 ft) and 120 m (400 ft) in advance of this curve. [These were 120 m (400 ft) and 105 m (350 ft).] They could be 25 m (75 ft) closer if 1.2-m (48-in) signs were used.

2. The rule of thumb, 90-m (300-ft) minimum spacing for signs [at 90 km/h (55 mi/h)] should be maintained to give clear warning and eliminate distractions. (The "No Passing Zone" sign is almost across the road from the curve warning signs.)

SITE #34

(DATE OF FIELD INVESTIGATION: 10–30–96)



* THREE OFF ROAD ACCIDENTS EVIDENT BY MARKS ON ROAD AND IN DITCH. VERY LIKELY THAT NOT ALL THE ACCIDENTS HERE ARE REPORTED.

CURVE DATA:

LENGTH ~ 140M
PI –> PC ~ 90M
(SUPER NOT FULLY DEVELOPED DUE TO SHORT LENGTH)

AVERAGE DAILY TRAFFIC VOLUMES:

MN ROUTE = 1,363 VPD
COUNTY ROUTE = 347 VPD

FIELD OBSERVATIONS

NOTE: ALL THE ACCIDENTS LISTED INVOLVED NB VEHICLES LOSING CONTROL IN THE CURVE AND RUNNING OFF THE ROAD (MOST INVOLVING YOUNG DRIVERS – IN THE SUMMER)

NOTE: THE CHEVRONS ARE NOT ON BRACKETS, THEREFORE, THEY ARE NOT AT THE BEST ANGLE FOR VISIBILITY.

* DROVE THIS AT NIGHT – FOR SB TRAVEL, ONLY TWO CHEVRONS WERE VISIBLE AND THERE WAS A BLANK SPOT AT THE INTERSECTION AREA

Collision Diagram

BMI # 34

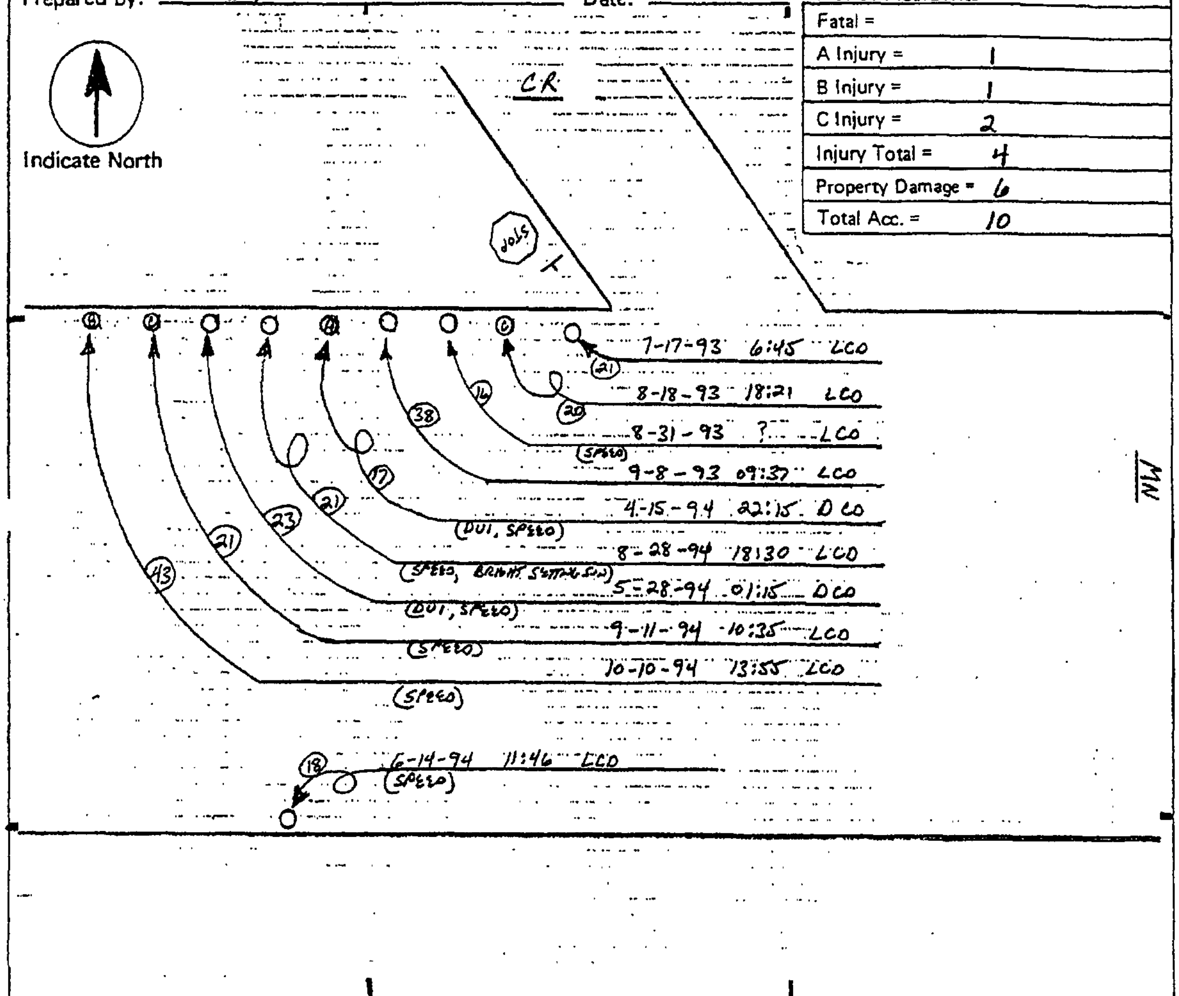
Location:

Time Period: 1993 + 1994

Prepared by: Gary Shannon   Date: 10-96

No. of Accidents	
Fatal =	
A Injury =	1
B Injury =	1
C Injury =	2
Injury Total =	4
Property Damage =	6
Total Acc. =	10

Indicate North



→ Motor Vehicle Moving Ahead
Motor Vehicle Backing Up
Motor Vehicle Out of Control
Pedestrian
Bicycle/Moped
Motorcycle
Fixed Object
Fatal Acc.
Ⓐ A Injury Acc.
Ⓑ B Injury Acc.
Ⓒ C Injury Acc.
○ Property Damage Acc.
Rear End Property Damage
Right Angle B Injury

Light:	Weather:	Surface:
L = Daylight (1)	C = Clear or Cloudy (1 or 2)	D = Dry (1)
DN = Dawn (2)	R = Rain (3)	W = Wet (2)
Du = Dusk (3)	S = Snow or Sleet (4 or 5)	S = Snow or Ice (3 or 4)
D = Dark (4, 5 or 6)	X = Other or Unknown	X = Other or Unknown
X = Unknown		

Example of Bicycle/Motor Vehicle Accident:

Injury Type   6-4-78   Du-C-D

Date = Time   Light – Weather – Surface

APPENDIX D: SAMPLE ROAD SAFETY-AUDIT CHECKLIST

Stage 3
Detailed Design

Checklist 3.1

General Topics

Project

Audited by

Date

Item	Issues to be Considered	Check	Comments
1 Changes since Stage 2	Check for any major changes in principle since the Stage 2 Audit was carried out.		
	Check that the conditions for which the project was originally designed still apply, i.e. there have not been significant changes to the surrounding network or area to be served, or traffic mix.		
2 Drainage	Will the new road drain adequately?		
	Is there a possibility of surface flooding or overflowing from surrounding or intersected drains and water courses?		
	Is pit spacing adequate to limit flooding?		
3 Climatic conditions	Do weather records or local experience indicate a problem (e.g., snow, ice, wind, fog)?		
4 Landscaping	Check the landscape design or planting species for a lowering of safety.		
	Is it likely to lead to a lower safety with mature or seasonal growth (e.g. through loss of visibility, obscuring signs, shading or light effects, leaves, flowers or seeds dropping on to the highway)?		
	Is "frangible" vegetation appropriate?		
	Consider pedestrian visibility in particular.		
5 Services	Does the design adequately deal with buried and overhead services?		
	Check the location of fixed objects or furniture associated with services, including for loss of visibility and check the position of lighting and other poles for accuracy.		
	Check the clearance to overhead wires.		
6 Access to property and developments	Can all accesses be used safely? Are there any down-stream or upstream effects from accesses, particularly near intersections?		

Item	Issues to be Considered	Check	Comments
7 Emergency vehicles and access	Has provision been made for safe access by emergency vehicles?		
	Check the design of medians and vehicle barriers, and the ability of emergency vehicles to stop without necessarily disrupting traffic.		
8 Future widening and/or realignments	If the scheme is only a stage towards a wider or dual carriageway, is the signing and design adequate to impart this message to drivers?		
	Is the transition from single to dual carriageway handled safely?		
9 Staging of the scheme	If the scheme is to be staged or constructed at different times, are the construction plans and programme arranged to ensure maximum safety and do they include specific safety measures, signing, also adequate transitional geometry for any temporary arrangements?		
10 Staging of the works	If the construction of this scheme is to be staged or split into several contracts check that these are arranged for maximum safety.		
11 Significant adjacent developments	Check that the design handles accesses to major adjacent generators of traffic and developments safely.		
	Check the need for screening against glare from lighting of adjacent developments.		
	Check that lighting or traffic signals on an adjacent road do not affect the drivers' perception of the road ahead.		
12 Stability of cut and fill	Do the geological conditions in the country through which the road is to be built pose significant threats to the safety of vehicle occupants?		
	Check batters for stability, potential for loose material.		
13 Skid resistance	Check the need for anti-skid surfacing on gradients or where braking or good road adhesion is essential.		
14 Maintenance	Check maintenance vehicles can be safely located.		

General Topics – contd.

Stage 3
Detailed Design

Checklist 3.2

Design Issues (General)

Item	Issues to be Considered	Check	Comments
1 Geometry of horizontal and vertical alignment	Check that the horizontal and vertical design of the project fit together comfortably.		
	Check the design for adequacy having regard to the function of the road.		
	Check the possibility of drivers not being able to read the road characteristics, visual illusions, etc.		
2 Typical cross sections	Are the lane widths, shoulders, medians and other cross section features in accordance with standard design or adequate for the function of the road?		
3 Effect of cross sectional variation	Check that there are no variations in cross section design which could affect safety, particularly where sections of existing highway have been utilised, or there have been compromises to accommodate accesses, etc.		
	Check where compromises have been made, e.g. at bridges or to avoid physical features.		
4 Roadway layout	Check if the total traffic management features (i.e. in addition to questions of horizontal and vertical alignment and cross section) are not likely to create unsafe conditions. This includes the installation of signs and markings both on the road and nearby to deal with changes in alignment, particularly where these are substandard.		
5 Shoulders and edge treatment	Check the safety aspects of shoulder provision, if any, including seal or metalled shoulders, the width and treatment on embankments and crossfall of shoulders. Are the shoulders likely to be used by slow moving vehicles or cyclists?		

Project

Audited by

Date

Stage 3
Detailed Design

Checklist 3.2

Design Issues (General) – contd.

Item	Issues to be Considered	Check	Comments
6 Effect of departures from standards or guidelines	Are there any approved departures from standards or guidelines which affect safety?		
	Are there any hitherto undetected departures from standards which should be brought to the attention of the designer?		
7 Visibility, sight distance	Are horizontal and vertical alignments consistent with the required visibility requirements?		
	Confirm the standard adopted for provision of visibility in the design is appropriate for the ruling or 85th percentile speed and for any unusual traffic mix.		
	Check sight lines are not obstructed by:		
	(a) Safety fences and barriers		
	(b) Boundary fences		
	(c) Street furniture		
	(d) Parking facilities		
	(e) Signs		
	(f) Landscaping		
	(g) Bridge abutments.		
	Check that railway crossings, bridges and other hazards are conspicuous.		
	Will sight lines be obstructed by temporary features such as parked vehicles in laybys or parked or queued traffic generally?		
8 Signs and markings	Has the design approach taken into account the provision of signs and road markings?		
	Are they adequately detailed so as to promote good traffic management and safety?		

Alignment Details

Item	Issues to be Considered	Check	Comments
1 Visibility, sight distance	Are horizontal and vertical alignments consistent with the required visibility requirements?		
	Confirm the standard adopted for provision of visibility in the design is appropriate for the ruling or 85th percentile speed and for any unusual traffic mix.		
	Check sight lines are not obstructed by:		
	(a) Safety fences and barriers		
	(b) Boundary fences		
	(c) Street furniture		
	(d) Parking facilities		
	(e) Signs		
	(f) Landscaping		
	(g) Bridge abutments.		
	Check that railway crossings, bridges and other hazards are conspicuous.		
	Will sight lines be obstructed by temporary features such as parked vehicles in laybys or parked or queued traffic generally?		
2 New/existing road interface	Have implications for safety at the interface been considered?		
	Include the accident rate and severity on the adjacent network, and the effect of sudden changes in the speed regime or access and side friction characteristics.		
	Does the interface occur near any hazard, i.e. at a crest or bend or where poor visibility or distractions occur?		
	Check that the change is effected safely where carriageway standards differ.		
	Check transition is safe where road environment changes, for example, urban to rural, fast to slow, or lit to unlit.		
	Check the need for advance warning.		

Project ....

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Date ....

Alignment Details – contd.

Item	Issues to be Considered	Check	Comments
3 Readability by drivers	Will the general type, function and broad features be recognised by drivers in adequate time for safety not to be impaired?		
	If new work is of higher geometric standard – is there clear and unbiguous advance warning of reduction in standard?		
	Is there need for a transition zone between higher standard of new road and lower standard of old road (especially perception of horizontal curvature, which is the primary determinant out of desired speed).		
	Check the approach speed and likely position of vehicles as they track through the project.		
4 Detail of geometric design	Check that the design standards are appropriate for all the new requirements of the proposed project.		
	Check for consistency of general standards and guidelines such as lane widths and crossfalls.		
5 Treatment at bridges and culverts	Check that the geometric transition from the standard cross section to that on the bridge is handled so as to promote safety.		

Stage 3
Detailed Design

Checklist 3.4

Intersections

Item	Issues to be Considered	Check	Comments
1 Visibility to and visibility at intersection	Are horizontal and vertical alignments consistent with the required visibility requirements? Will drivers be aware of the presence of the intersection (especially if facing a Stop/Give Way sign)?		
	Confirm the standard adopted for provision of visibility in the design is appropriate for the ruling or 85th percentile speed and for any unusual traffic mix.		
	Check sight lines are not obstructed by:		
	(a) Safety fences and barriers		
	(b) Boundary fences		
	(c) Street furniture		
	(d) Parking facilities		
	(e) Signs		
	(f) Landscaping		
	(g) Bridge abutments.		
	Check that railway crossings, bridges and other hazards are conspicuous.		
	Will sight lines be obstructed by temporary features such as parked vehicles in laybys or by parked or queued traffic generally?		
2 Layout	Check junctions and accesses are adequate for all vehicular movements.		
	Check swept paths to establish that the layout caters for the design and check vehicles and other road users.		
	Check safety of any unusual features.		
	Check need for crash barriers or pedestrian fences.		
	Check need for splitter islands and signs.		
	Check features for visibility intrusion e.g. crash barriers, pedestrian fences, signs and traffic signals.		
	Check safety where vehicles (including buses and taxis) may park or service premises within the intersection area.		

Project ....

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Date ....

Stage 3
Detailed Design

Checklist 3.4

Intersections – contd.

Item	Issues to be Considered	Check	Comments
3 Readability by drivers	Will the general type, function and broad features be recognised by drivers in adequate time?		
	Check the likely positions of vehicles as they track through the project. Is there anything misleading?		
4 Detail of geometric design	Check the layout adopted for traffic safety, compliance with standards or reason for variation, swept paths, ability to handle unusual traffic mixes or circumstances safely.		
	Check the correctness of the design approach speed and general likely position of vehicles.		
5 Traffic signals	Check visibility of signal heads. Can drivers be confused by seeing other signal aspects within the intersection or elsewhere?		
	Check need for high intensity signals and/or target boards if likely to be affected by sunrise/sunset.		
	Check markings for right turn vehicles.		
	Check need for pedestrian phases.		
6 Roundabouts and approach islands	Check that deflection angles of approach roads are adequate.		
	Check need for splitter islands.		
	Check that centre island is prominent		
	Check need for hazard markers and markings and that they are correctly located.		
	Check need for dedicated lanes.		
	Check that speeds are not likely to be greater than 50km/h (or lower in local street).		
	Check that roundabouts and islands are well lit.		
	Check pole location on central island and nearby kerbs.		

Intersections – contd.

Item	Issues to be Considered	Check	Comments
7 Other Intersections	Check the need for kerbed or painted islands and refuges.		
	Check intersection has adequate storage space for turning movements.		
	Check that staggered cross roads can accommodate all vehicle types and movements.		

Stage 3
Detailed Design

Checklist 3.5

Special Road Users

Item	Issues to be Considered	Check	Comments
1 Adjacent land	Check that access to and from adjacent land/properties is safe.		
	Consider the special needs of agriculture, movements of stock.		
2 Pedestrians	Check fencing is adequate on freeways.		
	Check need to deter pedestrians from crossing road at unsafe locations.		
	Check provision for pedestrians to cross safely at:		
	(a) Intersections		
	(b) Signalised and pedestrian crossings		
	(c) Refuges		
	(d) Kerb extensions		
	(e) Other locations.		
	Check the following for each crossing (bridges, subways, at grade) as necessary:		
	(a) Visibility		
	(b) Use by disabled		
	(c) Use by elderly		
	(d) Use by children/schools		
	(e) Need for pedestrian fencing on reservations and medians		
	(f) Signs		
	(g) Width and gradient		
	(h) Surfacing		
	(i) Provision of dropped kerbs		
	(j) Avoidance of channels and gullies		
	(k) Need for deterrent kerbing		
	(l) Need for lighting		
	(m) Sited to provide maximum use		
	(n) Can their use be avoided by crossing at grade or elsewhere?		

Project ....

Audited by ....

Date ....

Stage 3
Detailed Design
Checklist 3.5

Special Road Users – contd.

Item	Issues to be Considered	Check	Comments
3 Cyclists	Check needs of cyclists have been considered:		
	(a) At intersections (particularly roundabouts)		
	(b) On roads having speed in excess of 50 km/h		
	(c) Cycle routes and crossings.		
	Check shared cycleway/footway facilities including subways and bridges are safe and adequately signed.		
4 Equestrians and stock.	Check needs have been considered and adequately signed and catered for.		
5 Freight	Check needs have been considerred and adequately signed and catered for.		
6 Public Transport	Check needs have been considered and adequately signed and catered for.		
7 Road maintenance vehicles	Check needs have been considered and adequately signed and catered for.		

Stage 3
Detailed Design

Checklist 3.6

Signs and Lighting

Item	Issues to be Considered	Check	Comments
1 Lighting	Is the scheme to be lit?		
	Are there difficulties of illuminating sections of the road caused by trees or overbridges, for example?		
	Has the question of siting of lighting poles been considered as part of the general concept of the scheme?		
	Are frangible or slip-base poles to be provided?		
	Are any special needs created by ambient lighting?		
	Are there any aspects of the provision of lighting poles which would require consideration from the safety point of view in their being struck by vehicles (e.g. traffic islands)?		
2 Signs	Are sign gantries needed?		
	Are signs located at points to allow adequate readability?		
	Are signs located to limit visibility from accesses and intersecting roads?		
	Are signs appropriate to the drivers needs, i.e. destination signs, advisory speed signs, etc?		
	Have the safety aspects of signs been considered as part of the general concept?		
	Are there any aspects of the provision of sign posts which would require consideration from the safety point of view in their being struck by vehicles?		
3 Marking and delineation	Check that the appropriate standard of delineation and marking has been adopted.		

Project

Audited by

Date

Stage 3
Detailed Design
Checklist 3.7

Physical Objects

Item	Issues to be Considered	Check	Comments
1 Median barriers	Are median barriers necessary and have they been properly detailed?		
	Are there any design features such as end conditions which require special attention?		
2 Poles and other obstructions	Are there any poles located adjacent to moving traffic which could be sited elsewhere, (i.e. at the property boundary)?		
	Have frangible or breakaway poles been detailed?		
	Is the unprotected median widths adequate to accommodate lighting poles?		
	Check the position of traffic signal controllers and other service apparatus.		
	Are there any other obstructions which are likely to create a safety hazard and can they be mitigated or relocated?		
3 Crash barriers	Is a crash barrier provided where necessary and is it properly detailed?		
	Are there any features about the design or presence of the crash barrier which could create danger to any road user, including pedestrians?		
	Are the end conditions of the crash barrier likely to create a safety problem?		
	Is the guard fencing designed according to standards – end treatment – anchorages – post spacing – block out – post depth – rail overlap.		

Project

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Date

Item	Issues to be Considered	Check	Comments
4 Bridges and culverts	Check bridge barrier and culvert end walls for:		
	(a) Visibility		
	(b) Ease of recognition		
	(c) Proximity to moving traffic		
	(d) Possibility of causing injury or damage		
	(e) Collapsible or frangible ends		
	(f) The need to be able to see through bridge guard railing for safety purposes		
	(g) Signs and markings		
	(h) Connection of bridge railing to bridge posts		
	(i) Connection of approach barriers to bridge		
	(j) End post transition of stiffness between approach barrier and bridge end post.		

Physical Objects

Project

Audited by

Date

Stage 3
Detailed Design

Checklist 3.8

Construction and Operation

Item	Issues to be Considered	Check	Comments
1 Buildability	Check that traffic management provisions are adequate during construction period.		
	Check that site access routes are safe.		
	Check need for construction safety zones, including for overhead work.		
	Check need for restrictions on any road.		
	Check that the Police and other emergency services have been consulted.		
2 Operation	Check access to structures and road furniture is safe.		
	Check that the road or utilities in the road reserve can be maintained safely. Both road users and maintenance personnel should be considered.		
3 Traffic management	Check that the traffic management of the construction site has been adequately spelled out from the safety point of view, and that the transition from the existing arrangements to the construction site and from the construction site to the final layout can be effected safely, and has been adequately detailed.		
4 Network management	Check that all parking and clearway matters affecting road safety have been considered.		
5 Temporary traffic control and management	Check that the arrangements for temporary traffic control or management, including possible signals, temporary diversions including signing and lighting of the site have been adequately detailed from the safety point of view.		

Project

Audited by

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Stage 3
Detailed Design

Checklist 3.9

Any Other Matter

Item	Issues to be Considered	Check	Comments
1 Safety aspects not already covered	Safety auditors are to check for any issue or item not already covered.		
	This could include:		
	(a) Unusual events		
	(b) Special effects on land uses alongside		
	(c) Stock being driven onto or along the road		
	(d) The ability of the road to take over weight or over-dimension vehicles or other large vehicles – trucks – buses – emergency vehicles – utility/road maintenance vehicles		
	(e) The ability to close the road for special events in a safe manner		
	(f) The special requirements of scenic or tourist routes		
	(g) Signals not at intersections.		

Project ....

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Date ....

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