NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP Report 430

Improved Safety Information To Support Highway Design

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Report 430

Improved Safety Information To Support Highway Design

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Safety and Human Performance

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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FOREWORD

By Staff
Transportation Research Board

This report documents the findings of a project to identify improved means to collect, manage, and use crash, inventory, traffic, and other data to design safer highways. Improved safety information is essential to making effective design decisions and formulating sound policies for the design of vertical and horizontal alignments, cross sections, roadside treatments, and traffic controls. The contents of this report are, therefore, of immediate interest to highway and facility designers and those concerned with systemwide safety improvement programs.

Crash data have traditionally provided the basis for determining locations and causes of highway network safety problems. Aggregate analysis of crash data also provides the basis for defining general safety issues and the development of design criteria to enhance safety. Inventory data exists in most transportation agencies to cover a diverse set of roadway elements including alignment, pavement type and condition, traffic-control devices, roadside features, and access points. Unfortunately, the crash and inventory data upon which design decisions are made are often inaccurate (e.g., poorly located), fragmented, missing, inconsistent, incorrect, and/or unlinkable.

The emergence of new technologies such as global positioning systems (GPS), geographic information systems (GIS), hand-held computers, electronic clipboards, digital imaging equipment (e.g., digital video and digital orthophotography), multimedia software, and bar code and magnetic strip readers has opened new opportunities to acquire, store, access, and use pertinent information on crashes, roadway features, traffic, and environmental conditions. This research was initiated in response to the need to (1) evaluate the potentials of new technologies, (2) develop innovative concepts for designing safer roads, and (3) recommend fundamental architectures for improved safety-information resources to address the needs of highway designers.

The objectives of NCHRP Project 17-12 were to (1) define the critical information elements needed to support project- and policy-level decisionmaking in highway design and (2) develop the fundamental architecture for systems to acquire, store, access, and use the information. It was recognized that crash reports represent the primary and most direct source of information on safety performance, but other sources of information were considered in this research.

A research team led by The Traffic Institute of Northwestern University, Inc., of Evanston, Illinois, was selected to undertake the research, which began in early 1996. The research team included staff from Northwestern University; CH2M Hill, Inc.; and several resource consultants and advisors. In undertaking NCHRP Project 17-12, this research team provided (1) a comprehensive review of the critical safety data needs for highway design purposes; (2) an assessment of methods to gather and use data; (3) an evaluation of emerging technologies for collecting, processing, storing, and accessing data; and (4) conceptual designs for a design decision support system (DDSS) for safety that would be possible with improved safety information.

Concepts for the application of improved safety-information systems were based on the premise that accurate location information is fundamental and proposed methods for gathering information should be simple, accurate, and expedient. The project integrated the new technologies into concepts for DDSS for safety that can be integrated into computer-aided design and drafting (CADD) systems or other design tools like the FHWA's Interactive Highway Safety Design Model (IHSDM).

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The authors wish to thank the many people who helped contribute to this report. Much of the literature was searched and secured through the Reference Librarians at the Northwestern University Transportation Library. Additional effort was contributed by various staff members from CH2M Hill.

Information about state practices was generously supplied by the Governor's Highway Safety Representatives in all of the states. Their initial responses led to personal contact with more than 40 additional people located in many states to discuss specific programs and actions that contributed different or unique elements to use of safety in design of roadways. Special thanks is given to the Wisconsin Department of Transportation in a session directed toward learning how a specific roadway design incorporates and uses safety information in all phases from planning through construction.

Staff from both the Traffic Institute and CH2M Hill spent many hours assembling parts of the report and providing review and editing.

Finally, the panel assembled for 17-12 provided significant assistance in reviewing the various aspects of how highway safety information is used in design and construction. They added many insights that otherwise might not have been available.

IMPROVED SAFETY INFORMATION TO SUPPORT HIGHWAY DESIGN

SUMMARY

Providing for the safety of motorists has been a primary stated objective of highway design. It has been presumed that the role of safety in design has been reflected in the design policies and standards adopted by agencies. Safety is nominally a factor in most decisions involving alternative designs. The limited quality of safety data and the inadequacy of the data management and information systems, however, have limited the effectiveness of past efforts to reflect highway safety in design decisions.

NCHRP Project 17-12 examined the need for improved safety information for use in making highway design decisions. The research results, summarized here, show that substantial improvements are needed in the quality and quantity of safety data and in the tools available to the designer for their use if meaningful improvements in the design of safe highways are to be made.

The project tasks and their objectives were as follows:

- **Task 1: Identify items of information needed.** Using applicable literature, contacts with highway designers, and other sources, identify user needs for information (including attributes thereof and access to it) to support project- and policy-level decisions related to safety and highway design. Relate user needs to data elements required and issues associated with their acquisition and management.
- **Task 2: Establish advisory group.** Establish an advisory group to provide insight into current practices and emerging technologies and to provide feedback on proposals for improvement in collecting, storing, accessing, and using safety and highway design data.
- **Task 3: Critically review uniform accident reporting requirements.** Critically review efforts to develop or implement uniform crash reporting requirements. Document other exemplary practices for using safety information to support highway design.
- **Task 4: Review emerging technologies.** Identify and assess emerging technologies that can improve safety data collection, management, and use in support of highway design.
- **Task 5: Develop conceptual designs.** Develop a set of candidate conceptual designs for a system that will improve collection, storage, and use of highway safety data to support highway design.
- **Task 6: Create interim report.** Document the findings of Tasks 1 through 5. Present a set of candidate conceptual designs for improved highway safety data to support

design. Identify necessary revisions to, and determine the most feasible among, the candidate conceptual designs.

- **Task 7: Develop fundamental architecture for selected designs.** Develop details for selected conceptual designs (including analyses of effect on current systems and organizations) and address implementation issues.
- **Task 8: Prepare final report.** Document the entire research effort and produce a brochure that encourages agencies to adopt systems and programs to improve highway safety information to support highway design.

The literature review focused on several important, but necessarily limited, points because of the breadth of topics to be addressed. This report summarizes the important questions examined, including the following:

- At what points in the design process are safety data needed to generate information to support design decisions?
- In order to better reflect safety in the design process, what safety-related data are desired and are expected to be useful?
- What are the issues, and their potential resolutions, associated with collecting and managing the desired data?
- What are the issues, and their potential resolutions, associated with delivering the desired information to design decisionmakers in the most effective manner?
- How can these issues be resolved, especially through application of new or emerging technologies and through strategies directed toward organizational and institutional factors involved?

A brief summary of the findings on each of these questions is given in this section.

DESIGN PROCESS

Insights into the types of design decisions that require safety information were developed from the literature review, interviews with state design engineers, input from the Project Panel and the Project Advisory Group, and knowledge of the research team. Three levels of activity commonly occur within a highway agency: system planning, project design, and system management (see Figure S-1). This project focused primarily on project-level design activities, but also considered the other two levels.

For the three levels of activity, two basic types of safety information generally are desired:

1. Information to identify the existence and nature of safety problems at a location, and
2. Information to predict the consequent effect of a design decision on safety.

The findings of this project are based on the nature of information needed by the various users. The relationship among data, information, and users is discussed in detail. Evaluation of any strategy to improve information for a given user or type of user must consider potential effects on the full range of potential users of the data.

An important aspect of the use of safety information is the level of analysis and the intent of the analysis. As Figure S-1 demonstrates, transportation and highway agencies can use safety data to support a wide range of activities, including administrative and legislative issues, planning and design policy activities, programming of projects, and project-specific planning and design. For each level of analysis, different types of

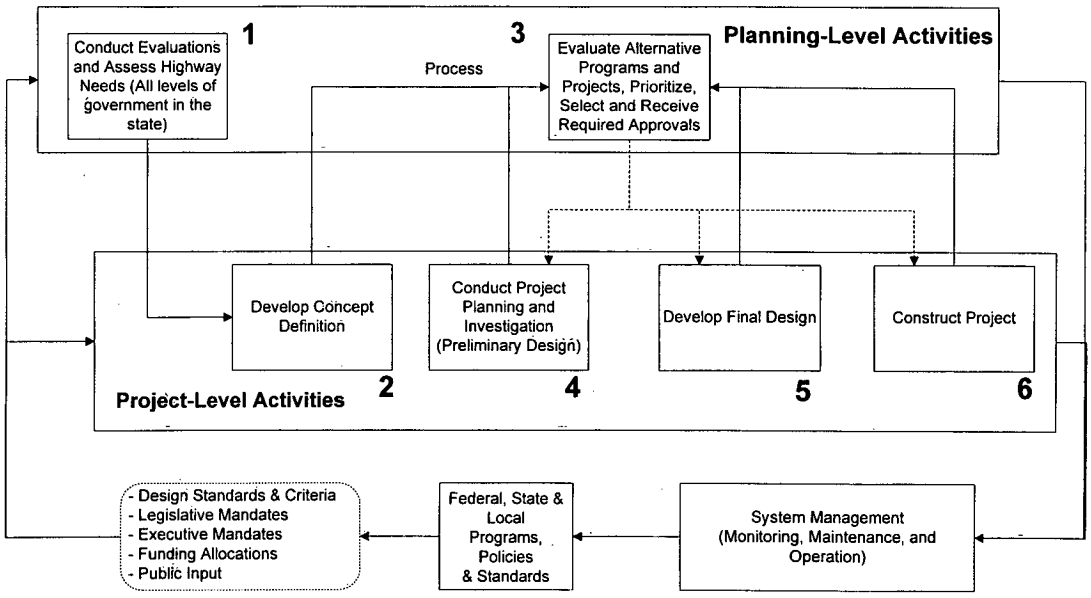

Figure S-1. Schematic of the highway planning and design process.

data are needed. Programming of planned improvements normally includes safety performance as one major criterion. Additionally, project-specific planning and design activities, problem definition, identification of a project "purpose and need" (necessary for an Environmental Assessment or Impact Statement), and alternatives development and assessment all require that safety data be used properly. Assessment of design details, including consideration of "design exceptions," often rests with an evaluation of the safety trade-offs associated with building a less than "full-standard" design. These activities require a wide range of data to generate the desired information. A data dictionary was developed to summarize the data needs identified in this research.

Current data and analytical tools often fall short in providing the designer with the means to address these information needs. As a result, design decisions often lack an adequate or accurate picture of safety. The research conducted on this project was structured to address the issues identified. This report presents those issues and identifies strategies that can be employed to help resolve those issues.

ISSUES ASSOCIATED WITH SAFETY INFORMATION

Safety is often not given adequate consideration in making design decisions because safety-related data are not of sufficient quality, appropriate information cannot be readily produced, and appropriate analytical tools are not available to designers. Regardless, designers wish to address safety in their work. The problems designers face in obtaining and using safety data result in these data not being given their proper weight in decision making. This relationship between confidence quantifying effects and the effects from design decisions is illustrated in Figure S-2.

Designers tend to give more weight to those factors about which they have the greatest confidence. These factors include estimates of construction costs and quantified right-of-way effects. Public opinions regarding alternative decisions also tend to carry weight in decision making. The designer often considers information about crashes

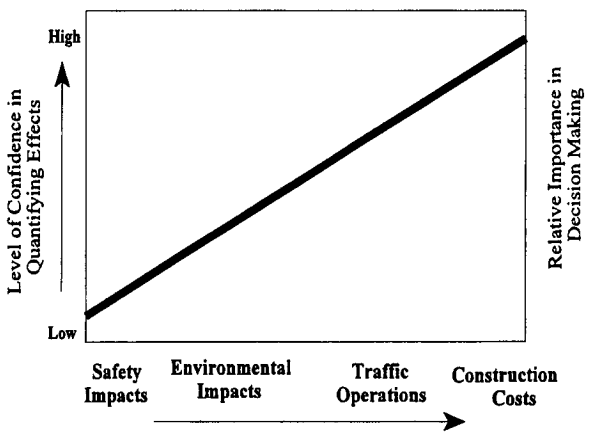

Figure S-2. Relative role of safety in design decisions.

(e.g., their locations, environmental factors, and causes) as incomplete, missing, or clearly erroneous. Typically, designers have neither the time nor the resources to correct the problems and so must proceed with information that is of lower quality than that related to other factors being considered. As a result, designers tend to lack confidence in the predictability or quantification of how alternatives affect safety, and safety inevitably becomes a secondary factor in decision making. Specific issues are described in the sections below.

Safety Data Collection Issues

Safety data problems exist with respect to the police crash report (PCR), the type and quality of data maintained that describe the highway environment, and dynamic data (e.g., traffic volume and speed). Data shortcomings can be attributed in part to the lack of focus on safety when procedures and protocols are established by agencies responsible for data.

The primary source of crash information is the PCR. In many cases, such reports do not exist, and, when they do, the information that the designer believes to be most important (e.g., the location of the crash) is missing. Because the reporting police officer has primary responsibility to secure the scene, see to the treatment of the injured, and minimize resulting congestion, he or she often may not take the time to properly locate the points of impact or record other roadway-related elements.

With respect to the roadway, data of critical importance to safety typically are not collected and maintained by highway agencies. For example, the character of the roadside is acknowledged to be among the most important factors affecting safety on two-lane rural highways; however, few states maintain records of roadside features or conditions that provide sufficient information for use in decision making. Most agencies also do not inventory geometric features (e.g., horizontal alignment, vertical alignment, and intersections) that researchers relate to crash frequency and severity.

Although traffic data are maintained by most agencies, the data generally are not of sufficient quality to support safety decisions. Traffic volume data for intersection movements are not usually available. Adequate information about vehicle speeds is often lacking. For example, the frequency with which traffic volume data are updated may be sufficient for pavement management systems, but not for characterizing use in safety analyses.

Safety Data Management Issues

The research also demonstrated the need to improve aspects of data management, including establishing links between data bases, using information not traditionally accessed by designers, and maintaining history files.

Valuable data (e.g., from maintenance records [such as those for guardrail replacement], pavement and bridge management systems, trauma records, and citizen complaints to police or highway agencies) are maintained by others for purposes other than highway safety. These data might be useful in safety analyses, but, because they are not accessible, they are not used. Such data could offer insights to designers or safety analysts, but are typically not linked to safety data systems.

Most agencies do not maintain long-term records of the safety history of a highway or of historical changes in geometric conditions, traffic volumes, or other related conditions for specific locations. Such data, maintained over a long time and accessible to designers, would be useful in evaluating the effectiveness of site-specific improvements and, thus would enhance decision making for future designs.

Furthermore, the analyst might not be able to generate information to make a connection between historical crash patterns and related conditions (for which data are available in the roadway inventory) because the location reference is often not precise enough or is missing. Even if determining the link were possible, achieving it would be time-consuming, and records often do not contain adequate information about longitudinal geometrics. If the user were to evaluate a change in geometry at a site, a time-series analysis would probably be appropriate, but this would require 10 years' worth of data. The roadway inventory, however, might not maintain history files, so the user could not be sure if and when related changes were made to the highway. Finally, the designer might not have available traffic data or other data that would be of value in considering design changes.

These are just a few of the difficulties to deal with when an attempt is made to use highway safety information to support highway design. This report addresses the issues and includes recommendations regarding a systems concept designed to integrate safety data into the design process and make it useful to the highway designer.

POTENTIAL RESOLUTION OF SAFETY INFORMATION ISSUES

The research proposed a comprehensive approach to addressing the above problems, including development of an institutional framework wherein safety decision making can be enhanced. Advances in technology in both data collection and management offer many cost-effective opportunities. Sensitivity to designers' safety-related data needs in data collection programs is part of the solution. Organizational strategies to upgrade the importance of safety information are recommended.

The Role of Technology

Regarding the application of technology, the research demonstrated that, despite recent technological advances, few agencies employ anything approaching the full range of technologies that could optimize their use of safety data. Technologies can be applied to data collection, management, and communications. With the advent of computer-aided engineering (CAE), highway agencies can build and maintain detailed inventories of their systems by direct reference to computer files of as-designed roadways. Of the 33 states contacted, approximately one-half (although not always the same

states) use portable computers, global positioning equipment, instrumented vehicles, and geographic information system-based data to help with data collection. Fewer than one-third use optical reading for forms and distributed databases, link crash reports and medical data, or use modeling tools or decision support systems. Overall, agencies are not taking full advantage of the powerful computer-aided tools now available.

Application of technologies offers the opportunity for agencies to improve the quality of data with less effort or cost than currently being expended. Traffic volume data gathering, for example, can take advantage of computerized signal systems that are in place and monitoring intersection turning movements, vehicle classification, and speeds. If captured and made accessible to a safety information system, such data could result in agencies no longer having to conduct expensive manual or other counting programs that yield less information.

Need for a Design Decision Support System

Given improved data quality and data management through strategies such as effective use of the latest technologies, the current highway design process still would lack a comprehensive means for incorporating safety information. Improved information might only leave the designer with the dilemma of how to deal with such information. The NCHRP Project 17-12 research team recommends the development of a design decision support system (DDSS) for safety to help designers make design decisions at each stage of the process.

The recommended framework for a DDSS provides for several elements, including user interface, a decision support module, an information presentation module, and a design analysis module. This proposed framework is shown diagrammatically in Figure S-3.

The user interface should be as intuitive as possible for end-users and managers. End-users (designers) primarily would interact with the system through the decision support module. This module would provide an "intelligent" core to the system. The information presentation module would contain the basic software needed to display information derived either directly from the data stores or generated from the design analysis module. Finally, the design analysis module would provide tools for analyzing existing and proposed designs and would be able to draw from the best analytical devices available at any given time.

The types of analytical tools discussed to this point are designed to facilitate identification of the underlying factors contributing to highway crashes. The tools are intended to allow the designer to investigate the data to the level of detail desired, by performing a series of inquiries, each of which can "drill down" further into the details available in the data set. In addition to these traditional analytical tools, the module would also deliver to the designer the results of analyses using methods potentially based on safety audit procedures. Safety audits might be used as a vehicle for summarizing and assessing the results from other design analysis tools available in this set. There also would be a series of analytical devices to test and assess a proposed design. Finally, analytical tools, such as those being developed by the FHWA's Interactive Highway Safety Design Model (IHSDM), would be included. The tools would include, but not be limited to, vehicle-driver dynamics simulation, human factors-based design analysis procedures, models for predicting the operational and safety outcomes of alternative designs, and economic analysis tools.

Development of the proposed system would evolve as funding became available, organizational and institutional requirements could be met, and technologies became viable. Establishing time frames for this development could be arbitrary, because the responsiveness of government would be difficult to project and the progress of technology

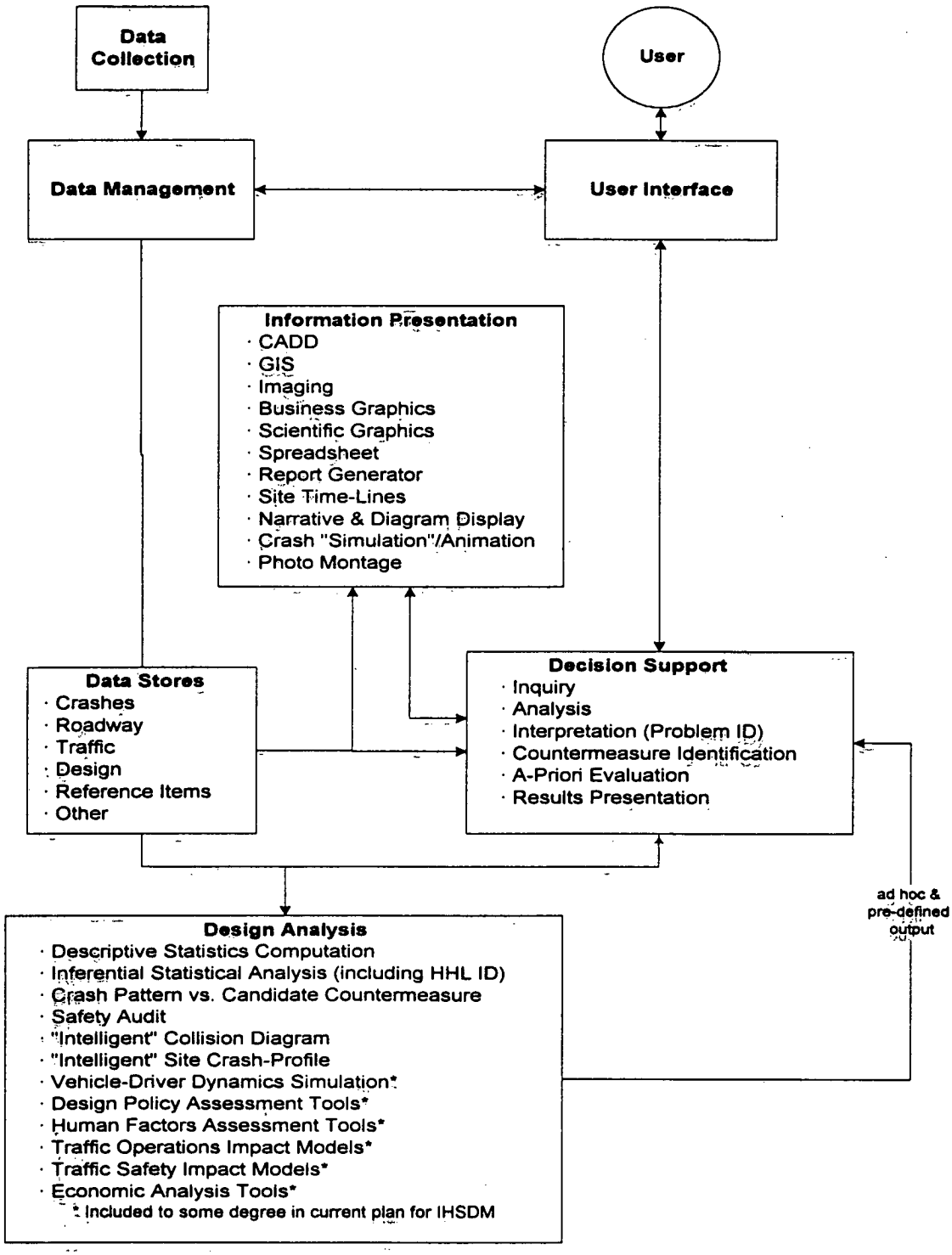

Figure S-3. Generalized concept for a design decision-support system.

would be difficult to predict (but is usually ahead of expectations where commercially viable applications are involved).

The DDSS would be structured to assist the designer at various stages of the process. It would be able to generate information at levels of detail from the most aggregate to the most disaggregate. The report demonstrates the drill down concept by diagramming and describing processes used in identifying locations considered especially hazardous.

Implementing the proposed system over time should produce substantial benefits to the highway design community and others. Examples are given in Figure S-4.

ORGANIZATIONAL AND INSTITUTIONAL CONSIDERATIONS

Even when technological tools are available, organizational and institutional issues may limit their usefulness. Such issues include lack of integration of data files, dependence on sources of data which may derive from organizations that are not oriented to the data needs of the design community, lack of integration of computer tools, and inadequate designer computer literacy.

Recommended organizational and institutional actions include the following:

1. *Policy Actions:* Giving safety data the status of "strategic enterprise data"; establishing safety performance measures; requiring state and local agencies to participate in safety data collection oversight; and allowing access to high-precision, high-level remote imaging for use in obtaining data for documenting the physical highway environment.
2. *Organizational Actions:* Reorganizing agencies to facilitate the efficient and effective collection, management, and use of safety data; establishing entities to provide specialized data and decision support services; establishing entities dedicated to quality assurance of data; and coalescing state and local agencies into a cooperative safety data collection and management function.

Current Practice	Becomes	Improved Practice Using the New System
Extensive manual assembly of safety data tabulations from different offices within and outside the design agency, requiring many hundreds of staff hours	→	Direct access to a comprehensive data warehouse, within a CADD/GIS environment
Manual inspection of hard copy of crash reports from microfilm record, to correct coding errors	→	Pre-screened data minimizes errors including proper location of crash; plus immediate access to digital images of crash reports within CADD/GIS environment
Labor-intensive translation of tabulations of key data into calculated fields and graphics using independent spreadsheets and graphics software into which data must be manually keyed	→	Integrated statistical routines, business graphics and advanced data-visualization software; including intelligent collision diagrams plotted on actual geometry and highway attribute time lines
Lack of historical traffic data and history of site geometry	→	Data warehouse with records of all available traffic counts, and a continual, up-to-date history of physical attributes of the site
Lack of safety models and limited flexibility of data systems to provide support for positions taken regarding the hazards at the site and the effectiveness of proposed improvements	→	A suite of design analysis models to assess existing and proposed designs from a variety of perspectives, making it feasible to produce a documented and defendable estimate of safety impacts of alternatives
Support for decisions regarding data to use, analysis of it, conclusions to be drawn, and arriving at recommended improvements comes from staff or specialists	→	A central decision-support function within the system to provide the user with guidance at every step of the analysis
Decision tools which are applied are done manually	→	A suite of decision tools using the latest developments in decision science are directly accessible with information generated by the system, based upon the previous work of the designer

Figure S-4. Examples of impact on safety analyses for a design project with implementation of the DDSS concept.

3. *Legislative Actions:* Establishing and authorizing data collection and management functions with oversight over enterprise-strategic data for users within the state, and enabling, through legislation, the implementation of real-time, on-board vehicle dynamics data collection from vehicles involved in crashes.
4. *Funding Actions:* Funding technological advancements, comprehensive research, and training in the use of safety data; establishing mechanisms for cooperative funding of strategic enterprise safety data; and establishing performance-based funding for highway projects.
5. *Training Actions:* Offering training for designers in principles, practices, and tools of safety analyses and on new safety information systems.
6. *Research Activities:* Continuing support of tools such as FHWA's IHSDM, developing and using additional tools and methods to support highway design, and committing to develop improved design guides and standards based on improved safety information.

CONCLUSIONS

The research team concluded that decisionmakers can have improved safety information to support highway design. To achieve this outcome, the design community should do as follows:

- Recognize the importance safety plays in making design decisions, the inadequacy of present methods for incorporating safety, and the need to improve and enhance methods for analyzing safety.
- Take an active role as part of the broader safety community to help define designers' requirements for safety data, and work with other users of safety data, in cooperation with collectors and managers of the data, to plan, design, finance, and implement systems that are useful for design purposes.
- Develop new ways of delivering information, using all the appropriate technology.
- Better prescribe and promote proper approaches to analysis and decision making.
- Embark on an ambitious program to demonstrate and develop the decision support systems that are needed, once improved information is available that justifies their use.
- Re-examine their institutional and organizational structure and environment to identify where barriers to positive change exist, and anticipate how organizational change must take place to maintain effective operations.

CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

INTRODUCTION

A passenger vehicle enters a heavily traveled section of a freeway using a ramp on the inside of a curve. The ramp is on a downgrade, and there is a retaining wall between the ramp and main roadway until just prior to the end of the merge. The vehicle in lane 1 does not see the entering vehicle until it is at the merging end. Because the entering driver does not use the full length of the acceleration lane and enters at a relatively low speed, the driver in lane 1 quickly moves to lane 2 to avoid this vehicle. However, there is an adjacent vehicle in lane 2. This driver swerves to the shoulder, strikes the median barrier, and rebounds into another vehicle in lane 2. The collision is serious, but both drivers manage to maintain enough control to move onto the left shoulder before coming to a full stop several hundred feet downstream from the ramp. A passenger is injured in one of the vehicles. The original entering driver already has moved beyond the area and is unaware of the crash.

What can be learned from this crash to make the particular location or similar ramps safer? What data about the crash are necessary to begin such a task? Who will supply the data, and how will it be accessed by the user? How will the user aggregate the data on this crash with data on other crashes in this area or similar areas? What types of analyses will the user wish to perform and what decisions are to be made as a result of these analyses? What will it take for the design-related factors to be identified?

If an analyst is attempting to employ highway safety data to establish design guidelines, that person would probably be interested in questions such as the following:

- What was the first harmful event, and where did it occur?
- What contributing circumstances were associated with the first harmful event?
- How severe was the crash?
- What were the subsequent events and their locations (to determine if combinations of design elements add to or reduce the seriousness of a crash)?
- What were the environmental conditions at the times and locations of the first and the most harmful events?
- What were the density, speed, and mix of traffic?
- Had there been previous problems, excessive maintenance, or complaints at the location?
- What were the geometric and cross-sectional dimensions at the location?

Other questions may be applicable, but the list above suggests issues to be considered in this type of analysis. A person studying this particular section of highway would be interested in many of the same data as the analyst seeking to establish design guidelines. Further details about the sequence of events also would be useful to a project-oriented study.

The primary source of crash information is the PCR. For the situation cited, however, the officer might report only the final locations of the vehicles that collided and might not collect data about the sequence of events that occurred. In some cases, the officer might not report the location with sufficient detail or accuracy to tag it for a location reference for the computer record. Although the officer might be required to indicate the type of geometry present at the crash location, he or she probably would record the geometric attributes requested for only the final locations of the involved vehicles. Because the officer has primary responsibility for securing the scene, seeing to the treatment of the injured, and minimizing resulting congestion, he or she probably will not take the time to locate the point of impact with the median barrier unless the crash involved a fatality or an injury potentially resulting in a fatality. Other elements related to the roadway also may be missed.

With such a scenario, the analyst might not be able to make a connection between the crash report and related data available in the roadway inventory because the location reference would not be precise enough or would be missing. Even if the link were possible, achieving it would be time consuming, and the record would not contain any information about the longitudinal geometrics. If the user were to evaluate a change in geometry at a site, he or she would, most appropriately, employ a time-series analysis that requires 6 to 10 years' worth of data. However, the roadway inventory might not maintain history files, so the user could not be sure if and when other changes had been made.

These are a few of the issues faced when an attempt is made to use highway safety information to support highway design. This report addresses the issues and includes recommendations regarding a systems concept designed to integrate safety data into the design process and make the safety data useful to the highway designer.

STRUCTURE FOR THE STUDY

Addressing the issues adequately requires consideration of each stage of the process to provide and use information. The stages include the following:

- Data collection and acquisition,
- Data entry and storage (management),
- Data access and information production, and
- Information use.

The data may be collected or acquired from several sources. Alternative sources may exist for the same basic information. Potential sources of data are as follows:

- PCRs,
- Roadway inventories (including photologs),
- Traffic count and operation records (including data from instrumented facilities),
- Maintenance records,
- Driver records,
- Vehicle records,
- Fleet maintenance records, and
- Local input (e.g., law enforcement reports, public comments and complaints, and local traffic reports).

The many barriers to use of potentially valuable sources include the following:

- Institutional,
- Technical, and
- Cost.

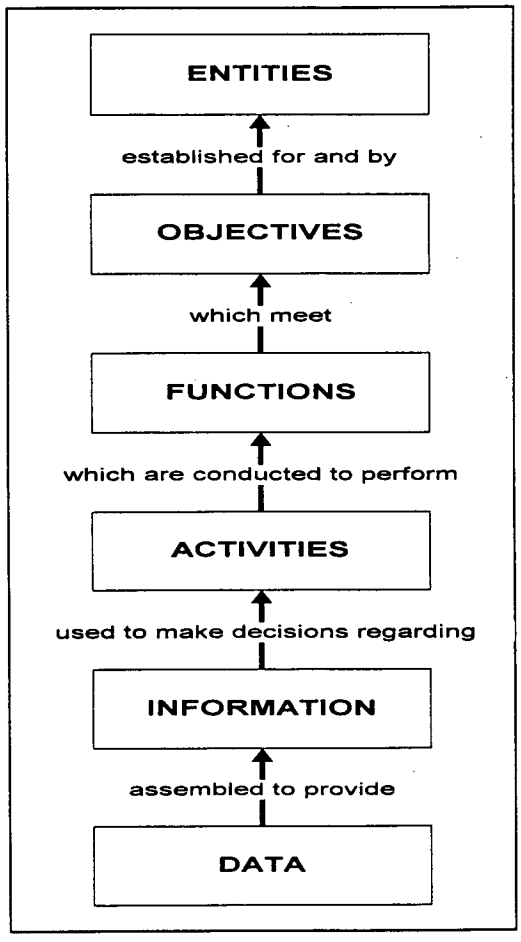

Figure 1. Data user relationship.

Institutional barriers can result from security concerns, privacy issues, and the proprietary nature of the data. Technical issues often concern how to link one data source with another—linking is critical to cost-effective use of multiple data sources. Location is often a key linking variable. Incompatible location referencing systems, inaccurate location data, and inflexible data management systems all represent barriers to success. Cost is often a function of the other barriers, but limited resources, common for today's agencies, often prevent investments that could make systems more cost-effective.

The findings of this project are based on the information needed by the various users. The relationships among data, information, and users is shown in Figure 1.

Evaluation of any strategy to improve information for a given user, or type of user, must consider the potential effects on the full range of potential users of the data. Examples of entities and their functions are provided in Figure 2.

How useful safety information is depends on the level of analysis and the intent of the analysis. Transportation or highway agencies can use safety data to support a wide range of activities, including administrative and legislative activities, planning and design policy activities, programming of projects, and project-specific planning and design. For each level of analysis, different types of data are needed. At the administrative and legislative level, aggregate data describing traffic fatalities, injuries, and property damage linked with other traffic data are used to support or defend expenditures of funds for safety improvements. These data may also be used to support proposed laws or regulations. Agency policies are also influenced by safety considerations (e.g., the formulation of design and construction standards and practices, policies such as application of access controls for new highways, and specific criteria for determining needs for improvements). Programming of planned improvements should include the consideration of safety performance. Finally, project-specific planning and design activities use safety data extensively.

Problem definition, identification of a project's purpose and need (necessary for an Environmental Assessment or Impact Statement), and alternatives development and assessment all require that safety data be used properly. Assessment of design details, including consideration of "design

Data User	Functions of this Entity
Law Enforcement Agencies	Enforcement of traffic laws (at all levels of government)
Traffic Safety Administration	Development of annual highway safety plans, including program funding
Transportation, Highway, and Public Works Departments	Programming, planning, design, construction, operation, and maintenance of highways
Motor Vehicle Administrators	Licensing, registration, and control of drivers and vehicles for highway use
Medical Providers (EMS Systems/Hospitals)	Management and treatment of highway trauma including emergency response and plans for patient receipt
Adjudication System	Administration of laws governing highway operation
Legislators/Regulators	Enactment of laws and regulations to develop and control the highway system; funding of transportation/highway programs; work with constituents to solve local problems
Insurers	Provision of insurance for road users
Schools (Public and Private)	Training highway users
Commercial Road Users	Commercial transport of goods and public transport of people
Vehicle Manufacturers	Design, manufacture, and repair of vehicles
Independent Research	Examination of causes of and potential remedies for crashes, but not as a part of other entities here
Other Interest Groups	Representation of special interests related to highway safety

Figure 2. Safety data users and their functions.

exceptions," often starts with an evaluation of the safety trade-offs associated with building less than a "full-standard" design.

The typical structure of a transportation agency and the typical project execution process complicate the use of safety data. Typically, crash data are the responsibility of a department, within the agency, that is separate from other user departments. In some cases, information (e.g., traffic volumes and roadway inventories) from multiple departments is needed to complete an analysis. The research team has found that agencies find assembling the information is cumbersome and time consuming. Moreover, in many agencies, the departments maintain separate, unlinked databases making detailed or thorough analyses nearly impossible.

The research conducted on this project was structured to address these issues. Each task is summarized below.

RESEARCH APPROACH

Task 1: Identify Items of Information Needed

Objective: Identify user needs for information (including attributes of the information and access to the information) to support project- and policy-level decisions related to safety and highway design. Relate these needs for information to the data elements required and to the issues associated with acquisition and management of the data.

Subtasks. A literature review was performed. An annotated bibliography and synthesis were developed. Operating agencies were surveyed about their use of safety data in design. With this background, the research team developed an initial statement of safety information needed to support highway design. This statement was an important foundation for the remainder of the work.

Task 2: Establish Advisory Group

Objective: Establish an advisory group to provide insight into current practices and emerging technologies and to provide feedback on proposals for improvement in collecting, storing, accessing, and using safety and highway design data.

Subtasks: Candidates for the group were selected on the basis of their knowledge of the various experience needed. This included persons familiar with the broader highway safety community and those with special expertise on emerging technologies potentially applicable to delivering the

needed information. The Advisory Group members are listed in Appendix A.

Task 3: Critically Review Uniform Accident Reporting Requirements

Objectives: Critically review efforts to develop or implement uniform crash reporting requirements, and document other exemplary practices for using safety information to support highway design.

Subtasks: Uniformity for crash reporting has been tried in different ways and at different scales over recent years. These initiatives were reviewed, and their effects were assessed. Additional personnel from operating agencies involved in design and use of safety data were contacted. These individuals were identified from Task 1 work and selected on the basis of the need for additional information. A revised statement of information needs was prepared on the basis of the work to this point. This revised statement included a list of issues associated with the collection, management, and use of safety data to support highway design as well as a description of the design process so that the uses for safety data could be readily identified. A preliminary concept for a design decision support system was developed as the means by which all of the needs for improved use of safety data for design could be met.

Task 4: Review Emerging Technologies

Objective: Identify and assess emerging technologies that can improve safety data collection, management, and use in support of highway design.

Subtasks: Using inputs from previous tasks and information obtained from discussions with members of the Advisory Group, emerging technologies that offered potential for resolving the issues identified in Task 3 were identified. A set of goals and objectives were established for the design decision support system for safety. Each technology was described in detail sufficient to permit the assessment of the applicability of the technology. An internal report was issued summarizing the findings.

Task 5: Develop Conceptual Designs

Objective: Develop a set of candidate conceptual designs for a system to improve collection, storage, and use of highway safety data in order to support highway design.

Subtasks: The system goals and objectives developed in the previous task were refined on the basis of the assessment performed. The concepts for the design decision support system were developed in greater detail, including how the system could be staged and a set of scenarios to demonstrate how the system could improve the current design process.

Task 6: Create Interim Report

Objectives: Document the findings of Tasks 1 through 5; present a set of candidate conceptual designs for improved highway safety data to support design; and identify necessary revisions to, and determine the most feasible among, the candidate conceptual designs.

Subtasks. An interim report summarizing the proposed system design was prepared and distributed to the Project Panel and the Advisory Group. A joint meeting of the two groups was held, at which the contents of the report were reviewed and the participants provided input toward revision of the concepts and recommendations. In addition, guidelines were established for the remaining work, including establishment of the format for the description of the fundamental architecture for the proposed design decision support system for safety. An initial set of development and demonstration projects was presented and discussed. The group provided further input by completing an assessment form for the proposed projects and by suggesting additional projects for consideration.

Task 7: Develop Fundamental Architecture for Selected Designs

Objective: Develop details for selected conceptual designs, including analyses of the effect on current systems and organizations and addressing implementation issues.

Subtasks: The fundamental architecture was developed for the proposed system design, following the guidelines established in the previous task. An implementation framework was detailed, including important organizational and institutional actions that would facilitate development of the system. This was reported to the Project Panel, and comments were received.

Task 8: Prepare Final Report

Objective: Document the entire research effort and produce a guidebook for encouraging agencies to adopt systems and programs to improve highway safety information used to support highway design.

Subtasks: Three products were prepared in accordance with direction from the Project Panel and NCHRP:

1. A research results digest, summarizing the project findings and outlining the recommended actions to start implementing the system. (This was to be developed in lieu of an implementation guide.)
2. A set of proposed development and demonstration projects that may be considered by funding agencies.
3. A final report.

STRUCTURE OF THE FINAL REPORT

Chapter 2 presents the project findings, including the state-of-the-art summary, a definition of the design process, identification of safety data needs, and a discussion of the issues associated with providing those data and producing information from them. Chapter 3 presents concepts for the proposed design decision support system for safety. System development is discussed from the perspective of staged integration of new technologies and a fundamental architecture for the system. The benefits of the system are described through analyses of how the new system would be more comprehensive and cost-effective than the current system. Concomitant benefits to others from the safety system are also identified. Chapter 4 summarizes several key conclusions as well as the proposed plan for an initial development and demonstration program. Appendixes A through K provide further detail on material covered in the body of the report.

CHAPTER 2

STATE-OF-THE-ART DESIGN AND SAFETY INFORMATION

INTRODUCTION

Over the years, providing for the safety of motorists has been a primary stated objective of highway design. It has been assumed that the desire for safety in design has been reflected in the policies and standards adopted by agencies. These policies and standards have evolved as knowledge about highway safety has evolved. Extensive research has been conducted on various aspects of the relationships among highway elements and safety, but this research has produced results of limited use. Methods have been developed to analyze designs with respect to principles of human factors that support safe driving. However, designers may not systematically apply the knowledge that exists because they either are not aware of it or do not have the adequate tools to apply such knowledge.

One of the first steps in this project was to synthesize what the literature says about the current status of safety in highway design. The research team's literature review included review of the work of two related projects of recent date.[1]

Given the breadth of the topics, the literature review had to be focused. Specifically, the team sought to answer the following questions:

1. What highway design elements and factors have been found to have a potentially significant relationship to highway safety?
2. What safety-related data are currently desired in conducting the design process?
3. What are the issues, and their potential resolution, associated with collecting and managing the desired data?
4. What are the issues, and their potential resolution, associated with delivering the desired information to design decisionmakers in the most effective manner?
5. Specifically, for the previous two items, what recent or emerging technologies may be considered for application?

Question 2 generally was not well addressed in the literature. The next section summarizes key findings regarding the relationship between highway design elements and traffic safety. This is followed by a discussion of the issues identified from the literature regarding the collection, management, and use of safety data of potential importance to designers. Next, there is a brief overview of new technologies that could improve safety information used to support highway design.

The comprehensive synthesis of the literature appeared as a separate report for this project; see, *Improved Safety Information to Support Highway Design, Synthesis of the Literature*. Evanston, IL: Northwestern University Traffic Institute and CH2M Hill. All of the references noted in parentheses in this report appear in Appendix B.

HIGHWAY DESIGN AND SAFETY

Roadway Design

Much of the literature describes how changes in one or more design features can affect safety by reducing crash frequency and severity. FHWA provided thorough summaries of important literature through 1991 (Cirillo, 1992). Six of the volumes in the FHWA set apply to this project. Discussions address safety relationships in the following areas of geometric design: horizontal and vertical alignment, cross section, junctions, roadside features, access control, and other roadway elements. In some cases, literature has addressed several of the topics simultaneously. Research and knowledge reflect basic differences in safety performance for different types of highways as defined by their functional classifications and environment (e.g., rural versus urban).

Horizontal Alignment

A substantial body of research has examined the safety effects of horizontal alignment on two-lane, rural highways in the past 15 years. The syntheses cited by Zegeer et al. (1992a) and Glennon (1987) established that accident frequency on two-lane, rural highway curves is related to the degree and length of curvature. Many curve-related crashes are single-vehicle, run-off-the-road. Both studies produced mathematical models useful for investigating potential high-hazard sites and for predicting the effectiveness of improving horizontal curvature.

Zegeer et al. (1992a) and Glennon (1987) identify other important relationships between safety and other highway features. Many curve-related crashes are single-vehicle, run-

[1] *Economic Analysis of Highway Safety Data*, FHWA Project DTFH61-91-00051, and "Effect of Highway Standards on Safety," *NCHRP Report 374*.

off-the-road. Shoulder width, quality of the roadside (e.g., sideslope and clear zones), and pavement friction are addressed by Glennon. Glennon also notes the importance of superelevation in curves. Zegeer generally confirms and expands on the findings related to roadway width and superelevation. His work also suggests a small but significant relationship between curve transition and crash frequency. He concludes, however, that, on arterial highways, spiral transitions are not safer for moderate to flat curves than curves without transitions.

The literature relating safety and horizontal curvature on other roadway types is limited. Dunlap et al. (1978) represents one of the earlier examinations of crash frequency and horizontal curvature along higher speed, limited access roads. However, this study of turnpike crashes noted interrelationships among horizontal and vertical alignment, pavement width and cross slope, and weather.

Less is known regarding crash frequency related to horizontal alignment on lower speed, urban facilities. Crash frequency on these higher volume, lower speed roads appears more closely related to intersections, access control, and cross-section features.

Vertical Alignment

According to Zegeer et al. (1992), the length and degree of vertical down slope and the frequency of crashes are related. No similar relationship appears with upslope. Increased speed and limited sight distances at the crest of the curve appear to play a role (see Mullins and Keese, 1961, and Raff, 1953).

Vertical alignment includes both the grade and vertical curvature. Two studies (Solomon, 1964, and Cirillo, 1968) determined that crash involvement rates increased for vehicles traveling at speeds that differed significantly from the mean speed of the highway. Combinations of grade and length of grade can produce measurable speed reductions for some lower powered vehicles. The potential for crashes has not been shown in a quantified relationship.

Similarly, there has been much study of safety related to stopping sight distance and vertical curvature. Theoretically, vertical curves that are too short can cause problems. Neuman and Glennon (1983) developed a model that described the potential safety relationship between limited stopping sight distance and crashes. Although cited in both *TRB Special Report 214* (1987) and McGee et al. (1994), the model has not been validated. *TRB Special Report 214* (on cost-effectiveness of geometric improvements) concluded that "reconstructing crest curves to improve sight distance can be cost-effective when a major hazard exists in the sight-restricted area, the design speed of the existing curve is more than 20 mph below operating speeds in the sight-restricted area and ADT is greater than 1,500." This conclusion was based on exercising the Neuman and Glennon model cited above.

More recently, research by Fambro et al. (1997) confirmed the relative sensitivity of crash frequency to vertical curve length. In general, Fambro's research confirms findings of others who have questioned the safety sensitivity of the current AASHTO design model for stopping sight distance and vertical curvature.

Finally, some studies have noted the interrelationship of multiple roadway elements. For example, severe vertical alignment coupled with changes in horizontal alignment (particularly sharp curvature) and intersections are more likely to produce crashes than the isolated aspect of severe vertical alignment by itself.

Cross-Section Elements Related to Safety

The term "cross section" includes the lanes, median, shoulders, and roadside character, including slopes and appurtenances. There is substantial difference in the safety performance of design dimensions for these features among the different types of highways: two-lane rural highways, multilane highways in rural and urban areas, and freeways.

Several major studies of cross-section elements have recently been completed and are generally accepted by the design community. Zegeer et al. (1994) completed a comprehensive study of more than 5,000 miles of two-lane highway in seven states. A mathematical regression model was developed that related crash frequency to lane width, shoulder width, and roadside condition. The model implies that widening lanes and shoulders can produce significant reductions in related crashes (single vehicle and some multivehicle types). Generally, the greatest effectiveness occurs in widening shoulders on narrow roads. A separate study by Zegeer and Council (1992) focused on cross-sectional safety relationships on low traffic volume roads (i.e., those with ADT of less than 2,000 vpd). Here, the findings were that total width of lanes plus shoulders of 28 to 30 ft were associated with lower rates of crashes than narrower roads (see also Golstine, 1991). Widening shoulders on very narrow roads was found to be more effective than widening lanes. An interesting finding of the Zegeer et al. study was that narrower road and shoulder widths for lower volume roads appeared cost-effective. These findings were eventually translated into revisions to AASHTO design policy recommendations for lane and shoulder width. Catchpole (1990) examined the effects of sealing shoulders on crash reduction in Australia.

Also focusing substantial attention on cross-sectional elements was *TRB Special Report 214* (1987). Findings were primarily based on information derived from studies of two-lane facilities. They concluded that the effectiveness of lane and shoulder widening is strongly influenced by traffic volume. Not only can collisions be reduced, but travel time can be improved.

Clear zones, horizontal sight distance, abutments (bridges and overpasses), culverts, and side slopes have received significant attention in the literature. Unlike issues related to

cross-section, alignment, intersections, and access control, none of the FHWA volumes related to highway safety were devoted specifically to roadside elements. Ross (1995), however, traced the evolution of roadside safety from the 1960s, when it was first recognized as a problem that should be treated as a separate component of highway safety, to the present. This review described seminal studies, legislative acts, and noteworthy actions directed toward the goal of achieving a forgiving roadside. However, as Viner (1995a) notes, the reduction in crash losses through roadside safety improvements needs to be weighed against the costs of producing those improvements.

Safety relationships for cross sections on a multilane highway are different from those for two-lane highways. Efforts have been relatively unsuccessful in establishing lane width and shoulder width safety relationships for such facilities. This, in part, arises from the relative infrequency of multilane roads with very narrow cross-sectional dimensions. The important features noted by several studies are the presence and width of the median on multilane roads. On the other hand, the importance of medians (both presence and width) in reducing the frequency and severity of head-on crashes has been confirmed by much recent research.

Harwood (1995) studied the safety and operational characteristics of multilane suburban roads and found that a five-lane design, including those with two-way left-turn lanes, had significantly lower crash rates than otherwise comparable four-lane undivided roads. This work noted the importance of considering driveway type and frequency and intersection frequency as well as median type. More recent work by Bowman and Vecellio (1994) has looked at the effect of roads with and without medians in central business districts as well as suburban areas. This work focused on crashes involving pedestrians and found that roads with raised medians and even TWLTL flush medians had lower rates of crashes involving pedestrians than undivided multilane roads.

In recent years, there has been interest in the safety effectiveness of reallocation of the available cross-section width on urban freeways. Studies of congested urban freeways nationwide by McCasland (1980) indicated that reducing lane widths and eliminating or narrowing shoulder widths to add one more lane actually improved their safety performance. More recent NCHRP research on the same issue produced mixed results. Of the sites studied by Curren (1995), some produced greater crash rates and others reduced crash rates following implementation of narrower dimensions on freeways. Curren concluded that narrowing the freeway lanes should not be viewed as a viable strategy for extensive reconstruction projects.

Road Surface

Another aspect of the road is its surface. Studies by Papleontiou et al. (1991) and Limotti and Hamblet (1989) have not been able to discover relationships between road friction and the likelihood of crashes. Craus et al. (1991) examined a wide range of elements contributing to crashes in Israel. They suggested that enough relationship existed between road surface and crashes that improving the coefficient of friction could reduce crashes on the interurban network. Not discussed by Zeeger et al. (1992a) was how drainage affects the surface.

Passing Lanes

In a recent simulation of Ohio two-way roads, Wu and Rogness (1995), through the use of models, showed that the use of passing lanes could help reduce both crashes and delay. In a state where 48 percent of the roadway is two lane, the findings are important, even though the state has not designed such lanes. Study of two-lane roads is becoming increasingly important, particularly around major metropolitan areas. Housing developments have expanded so this type of road, which once carried low volumes, is now handling heavy volumes. Funds and land are not available to upgrade the roads to multiple lanes or to control access.

Junctions

The term "junction" refers to intersections, interchanges, and at-grade railroad crossings. Interchanges also have been studied as part of the clear zone and placement of objects, such as light poles, which can be struck. At-grade railroad crossings will be examined in the next section, which is devoted to road design and other forms of transportation.

Intersections typically are among the most important features of the highway system in terms of safety. Research projects over the years have established that the design of the intersection, including turn lanes, channelization, type of traffic control, available sight distance, and presence of other confounding geometry, are all contributors to crashes. Studies have shown that intersections with left-turn lanes experience fewer collisions than those without. The severity of crashes and distribution by type are related to the type of traffic control present and the location of the intersection. Signalized intersections tend to have fewer right-angle crashes but greater numbers of rear-end crashes than stop-controlled intersections. Some studies have related the availability of intersection sight distance to crash frequency. More recently, a study by Belanger (1994) modeled the rate of crashes at unsignalized intersections as a function of the sum of entering volumes with no other geometric features. Bonneson and McCoy (1993) also modeled the frequency of two-way stop-controlled intersections as a function of the intersecting volumes only.

Crashes at intersections continue to serve as a focus for research. According to Kuciemba and Cirillo (1992) in their

review of literature for the FHWA safety effectiveness summaries, intersection-related crashes have been increasing over time. Such crashes currently account for more than 50 percent of reported crashes. However, the percent of fatalities resulting from such crashes has been decreasing. No work has been found that attempts to determine why fatalities have decreased even with increasing crashes. Also, Kuciemba and Cirillo are not clear regarding what has been included as "intersection" crashes in their value of 50 percent. Increasing congestion, for example, could result in more crashes related to, but not at, intersections. Representing the largest portion of collisions are signalized intersections, but they also carry the highest volumes (Bhesani, 1991). The conclusion reached by Kuciemba and Cirillo is that careful consideration should be given to all facets of intersection design, including traffic control.

Finally, several researchers have examined the issue of stop versus yield control. Polus et al. (1985), in a study critical to the understanding of intersection control, found that increasing the degree of control from yield to stop also increased the number of collisions. The suggestion was that the lack of adequate crossing gaps were handled better by motorists whose vehicles were in motion (at a yield sign) than when starting from a stop. Todd (1993) also examined the issue of stop versus yield from the use of warrants and concluded that not only sight distance, but gap acceptance needs to be addressed in the warrants. What is important is that shorter gaps could be accepted by rolling vehicles, which might help explain why yield intersections appear to perform more safely.

Roadside Objects Including Bridges

Australian researchers have taken particular interest in the contribution of bridges and culverts to crash losses. Of 155 crashes studied in Victoria, 110 involved either a tree, bridge, or culvert (Armour et al., 1989). Ogden and Howie (1990) have recommended that low-cost treatments be applied to many bridges rather than expensive treatments at only a few. Although the improvement may not result in as substantial a dollar savings for any one crash, a greater savings will be realized because the treatments will reduce losses arising in a large number of such crashes.

Access Management

Managing access is recognized as having a fundamental effect on the safety performance of a highway. Early research in the 1960s, confirmed by experience nationwide, shows that controlled-access facilities experience lower crash rates than those without full access control (Cirillo et al., 1969).

Research in more recent years has focused on the safety effects of driveway access to arterial streets. Harwood (1995) modeled crash rates on suburban arterials as a function of, among other factors, the number of driveways per mile and the character of the adjacent land use. His study confirmed the safety effectiveness of two-way, left-turn lanes for two-lane as well as four-lane arterials with driveway activity. Earlier research for the FHWA by Glennon et al. (1975) modeled driveway crashes per mile as a function of driveway frequency and traffic volume. Further, the literature suggests that knowledge of driveway density, usage, and median treatments is essential to understanding the safety of arterial highways.

Summary of Safety Research Related to Geometric Features

There has been a substantial investment in research over the past 30 years to investigate the relationships among highway geometric features or their dimensions and accidents. Many studies have been performed with the objectives being the development of mathematical models to describe the sensitivity of crash frequency as a function of design dimensions and other nongeometric factors, such as traffic volumes. Model development has been intended to fulfill one of two basic objectives: (1) to enable the evaluation of "cost-effective" geometric countermeasures to perceived problems and (2) to further the refinement of AASHTO and state geometric design policies, standards, and criteria. In both cases, the intention of modeling has been to "predict" accident occurrence (given a change in the design of a dimension for one or more geometric features).

The research community views much of the safety research on geometric features to be, at best, a mixed success. Many of the studies cited earlier produced models with only marginally acceptable results. Even the best conceived and executed research studies have produced findings in which great data variability is found, predictive capabilities are limited, or results are not considered statistically reliable.

Although there is debate within the highway research community about the value of previous research, there is consensus on the following key points:

1. Roadway, vehicle, driver, and environmental factors all contribute to highway safety. Even the best geometric research studies produce only modest predictive capabilities. Increasingly, the view is that, in general, roadway geometric design features probably contribute no more than one-third of the explanation for crashes and, perhaps, much less than that for certain situations or highway types.
2. The influence of roadway design on crashes is complex, probably more so than most previous modeling efforts indicate. Interactions among multiple variables are undoubtedly important factors, yet few research studies have had the resources or data quality and quantity to enable such interactions to be investigated.

3. Despite the above, the research provides useful clues to accident causation. Used in combination with human factors research and operational research, the information base describing the safety of highway design is considerably greater than what existed 30 years ago.
4. Caution is necessary, however, in predicting specific safety performance for a given location or feature. The applicability of safety research is generally limited to general or broad geometric design policy issues. Accident model application to specific locations or individual problems should be done with extreme caution.

The design community, in many respects, views safety research with even greater skepticism than the research community. Designers' anecdotal evidence of what is safe or not safe often conflicts with the research. Much of the available safety research is not understood or referenced by designers and, hence, goes unused. Finally, many designers do not trust the applicability of safety studies to their projects because the designers lack confidence in the information available to them to make the proper judgments.

Despite their skepticism about safety research, most designers believe that safety is at the core of the design standards and practices they use and that the reasons for given design dimensions, practices, and so forth are grounded in safety. This results in an interesting problem as well as an opportunity that is central to the issue of improved safety information related to highway design.

Table 1 summarizes the current state of knowledge regarding the known or suspected relationship between safety and the range of geometric and traffic features. Table 1 reflects the research team's judgments of the literature summarized above and presented in Appendix D. Table 1 also illustrates the significant disparity between that which is "known" and that which is presumed regarding safety and design dimensions. The disparity may have any number of explanations. Some believe that the design community overestimates in many cases the true safety sensitivity of certain design elements. Others maintain that the lack of known relationships is largely a function of imperfect or incomplete knowledge, which stems, in part, from data quality issues. Regardless of one's view, it is clear that the design community cannot claim to design optimally for safety until a better understanding of safety effects is reached and translated into actual design solutions.

Many in the design community and research field have not given up on the value of attempting to model accident causation. In their view, limitations and problems suffered by previous research efforts can be attributed to the data quality and quantity problems noted below.

In the highway design community, most agree that, regardless of the state of knowledge or confidence in the research, the importance of providing for safety in design cannot be ignored. The challenge is thus to optimize the quality and availability of the necessary safety information to enable designers to improve their knowledge and capabilities in applying safety information to design problems. There is, therefore, the possibility that this study will provide input that would not only support safer highway design, but would advance the state of the art in crash prediction research efforts.

A review of much of the research on highway safety reveals researchers confronted by common problems—problems with the collection, maintenance, and use of the safety data. The safety data of interest include descriptions of each crash, characteristics of the roadway environment, and descriptions of traffic flow.

Issues of Crash Data Use

Several issues relate to the use of crash data for highway safety design. One issue concerns the problems that originate with the collection and storage of data from the PCR. A second, and perhaps the most important, issue is the quality of the crash data collected by the police and that obtained by a design agency for the roadway inventory. Issues related to use of high-hazard locations (HHLs) include the methodology used to determine the locations and assigning dollar costs to crashes as a means of selecting those locations' corrective actions.

Collection and Storage of Data

The PCR is the primary resource used by the safety community to document the existence of unsafe conditions. Several factors, however, often limit the usefulness of the PCR. One overriding issue is the quality of the data vis-a-vis its use in highway design. The reporting quality of police-based reports is particularly a problem for highway design uses of the data, because the officer is neither trained in, nor oriented to, highway design needs or concerns. Perhaps the best example of this involves the location of the crash about which a designer would require more accurate information than is often provided by the patrol officer.

Even though some data derived from PCRs are not always suited for use in roadway analyses, a report from the 1990 Conference on the Collection and Analysis of Highway Safety Data indicated that personnel involved in highway safety, including the engineers, do not take full advantage of the data that are available because of institutional barriers, inconvenience, and lack of archiving. Institutional barriers often are the result of an unwillingness to share databases. Although confidentiality laws may play a role in the reluctance to distribute data from crash files, the reluctance to share data is more likely to arise from a concern that the user will "misinterpret" the data. Managers of the data are concerned that "uninformed" users will draw incorrect conclusions, thereby undermining the credibility of the data.

(*text continues on page 23*)

TABLE 1 Summary of known relationships between highway safety and design and traffic features

Element	Sensitivity of Design Element to Safety			Normal Range in Design	Stability of Feature Over Time
	2-Lane Rural	Multilane Arterials	Freeways (Controlled Access)		
CROSS SECTION					
Traveled Way					
Number of Lanes	N/A	⊕	◗	2-10 (Freeways)	Very High
Width of Lanes	●	◗	◗	3.0 to 3.6 m	Very High
Width of Median	N/A	●	●	0 to 20 m	Very High
Type of Median	N/A	●	●	Open, Flush, Mountable, Raised (Barrier)	Very High
Type of Pavement	◗ (paved vs. unpaved)	N/A	N/A	Paved, Unpaved	Very High
Normal Cross slope	⊕	⊕	⊕	1% to 3%	Very High
Surface Condition	◗	⊕	⊕		Moderate
Roadside					
Width of Shoulder	●	◗	◗	0 to 3.6 m	Very High
Type of Shoulder	⊕	⊕	⊕	Paved vs. Unpaved	Very High
Sideslope	●	●	●	1:2 to 1:6	Very High
Offset or Clear Zone	●	●	●	0 to 15 m	Very High
Type of Barrier	●	●	●	Guardrail, Concrete Barrier, Curb	High to Very High
Type of Appurtenance(s)	●	●	●	Utility Pole, Tree, Mailbox, Light Standard, etc.	High to Very High
LONGITUDINAL ALIGNMENT					
Horizontal Curvature					
Radius of Curve	●	⊕	⊕	Tangent to 200 m (low speed roadway)	Very High
Length of Curve	◗	⊕	⊕	20 m to 1,000 m	Very High
Type of Transition	◗	⊕	⊕	None, Spiral	Very High
Superelevation in Curve	◗	⊕	⊕	0 to 12%	Very High
Distribution of Superelevation	⊕	⊕	⊕	50% to 100%	Very High
Vertical Alignment					
Grade	⊕	⊕	⊕	<0.5% to 10%	Very High
Length of Grade	⊕	⊕	⊕	0 to > 2,000 m	Very High

TABLE 1 Summary of known relationships between highway safety and design and traffic features (*Continued*)

Element	Sensitivity of Design Element to Safety			Normal Range in Design	Stability of Feature Over Time
	2-Lane Rural	Multilane Arterials	Freeways (Controlled Access)		
Curvature					
Type	⊕	⊕	⊕	Crest, Sag	Very High
Length	⊕	⊕	⊕	50 m to 500 m	Very High
JUNCTIONS					
Intersections					
Presence/Location	●	●	N/A	Varies	Very High
Type of Traffic Control	●	●	N/A	No Control, Stop, All-stop, Signal	High
Channelization					
Turn Lanes (Presence)	●	●	N/A	Left, Right Turn Lanes	Very High
Median Openings	N/A	◗	N/A	Varies (3 to 5 per km)	Very High
Angle of Intersection	⊕	⊕	N/A	90° to 45°	Very High
Sight Distance/Sight Triangle	◗	⊕	N/A		High to Moderate
Driveways (Access Control)	⊕	◗	N/A	Varies—0 to over 40 per km	High
At-grade Railroad Crossings					
Presence/Location	●	●	N/A	Varies	Very High
Type of Control	●	●	N/A	No Control, Lights, Gated, Barrier	Very High
Interchanges					
Presence	N/A	●	●	Varies	Very High
Type of Interchange	N/A	◗	◗	Diamond, Cloverleaf, etc.	Very High
Design of Ramp Terminals	N/A	●	●	20:1 Diverge for Exit 50:1 Merge for Entrance	Very High
Design of Ramps Proper	N/A	⊕	◗		Very High
Grade Separations					
Feature Over/Under	□	□	□	Roadway, Railroad, Waterway, Pedestrian Crossing	Very High
Width of Roadway Over	◗	⊕	⊕	Varies	Very High
Length	□	□	□	Varies 30 m to over 1 km	Very High
Vertical Clearance	⊕	⊕	⊕	4.0 m to 7.0 m	Very High
Offset to Abutment/Substructure	◗	◗	◗	<1.0 m to 10 m	Very High

(*continued on next page*)

TABLE 1 Summary of known relationships between highway safety and design and traffic features (*Continued*)

Element	Sensitivity of Design Element to Safety			Normal Range in Design	Stability of Feature Over Time
	2-Lane Rural	Multilane Arterials	Freeways (Controlled Access)		
TRAFFIC CONTROL					
Posted Speed Limit	⊕	⊕	⊕	60 km/h to 120 km/h	High
Presence of Lane and Edge Markings	◗	⊕	⊕	Varies	Moderate
Intersection Traffic Control	◗	◗	N/A	No Control, Stop Control, Signal Control	High
Presence of Lighting	◗	◗	⊕	Continuous, Spot, None	Very High
Parking and Loading Zones	⊕	⊕	N/A	Varies	High
Warning and Regulatory Signing	◗	◗	⊕	Varies	High
TRAFFIC OPERATIONS					
Traffic Volume					
ADT	●	●	●	<100 vpd to >100,000 vpd	Low
24-Hour Distribution	⊕	⊕	⊕	Varies	Low
Vehicle Classification	⊕	◗	◗	Varies	Low
Monthly Distribution	□	□	□	Varies	Low
Turning Movements	◗	●	N/A	At Intersections (Left, Right)	Low
Operating Speeds					
Speed Distribution	◗	⊕	⊕		Low
ADMINISTRATIVE					
Jurisdiction	□	□	□	N/A	High
Functional Classification	□	□	□	N/A	High

Legend

● The presence or range in design dimensions of the feature are known to influence crash frequency and/or severity, within the normal range in design.
◗ The design of the feature is presumed to influence crash frequency and/or severity; research has established only weak relationships, or current evidence is conflicting.
⊕ The design feature is presumed by current practice to be related to crash frequency and/or severity but research has not successfully demonstrated a relationship within the normal range in design.
□ The design feature or its dimensions are considered unrelated to crash frequency and/or severity within the normal range of design.
Very High Once constructed, the design feature or its dimension remains unchanged for many years. Changes would be associated with a major reconstruction or construction effort.
High Once constructed, the design feature, dimension or element generally remains unchanged over time. Minor and/or infrequent maintenance activities may change conditions.
Moderate The design feature or its dimensions may significantly change over time due to environmental conditions.
Low Feature or element is not constant over time. Data describing it require regular updating.
N/A Not applicable.

Inconvenience to the designers also limits how much use is made of available data. Staff engineers working in a design office may wish to inspect one or more PCRs, however, to do so typically would require them to leave their office, travel to the police station or other outside location, and search through paper files for the proper location. The extra effort and cost to obtain information that may be "helpful" but not completely necessary often results in the designer simply not making the effort or not having the necessary time to be able to make the effort.

Lack of archiving also limits data accessibility. Roadway inventories often contain only the most current status of the roads. Historic data have been purged from the files and may or may not be available in paper form. Crash data are sometimes removed after 2 or 3 years because of lack of adequate computer storage space. Lack of archiving can eliminate the possibility for conducting studies of long-term change.

Dimensions of Quality

The FHWA economic analysis of highway safety data recently completed by the Traffic Institute has highlighted literature applicable to the issues of quality and data collection (Pfefer et al., 1994). Many of the quality issues, even though considered only for crash reporting, also apply to roadway inventory. These issues relate to collecting, reporting, and storing data for later use. At each step of the process, any of the dimensions of quality can be compromised.

Quality is difficult to quantify—it can include coverage, accuracy, completeness, precision, consistency, and timeliness. Furthermore, the rating of the quality of a given set of data may vary according to the user and use of the data. One user's accuracy requirements may differ significantly from another's, or one user may not need as wide ranging a set of information about each crash as another. (See Figure S-1, which gives the designer's view of dimensional accuracy with respect to each roadway feature.) The result is an almost infinite number of quality requirements from users—this can result in ambiguity about the term itself.

In the literature, coverage, accuracy, and consistency are the key quality dimensions that have attracted the most attention. Precision, completeness, and timeliness tend to be discussed explicitly in reviews of specific traffic-record systems. Suggestions for improvement in the systems have appeared in many of the National Highway Traffic Safety Administration's assessment of state-level record systems (Brown and McCreary, 1991).

Coverage is the degree to which the entire universe of traffic crashes is captured by the system. Coverage is a function of several factors. Reporting levels are established by agencies so that low-severity crashes are not required to be reported by the police, thus saving the police time and costs. There are many variations in definition of threshold. Estimated cost to repair property damage is commonly used to establish reporting level; injury severity may also be used.

Differences among jurisdictions in their coverage of crashes is one of the greatest barriers to large-scale highway safety research studies. It is often impossible to combine databases from multiple agencies because they differ in the reporting thresholds for the underlying crash data.

Accuracy is a significant concern because errors in crash reporting are common, particularly for data such as occupant restraint usage, injury, severity, location references, and vehicle identification numbers. The results of a survey based on 35 respondents from 100 randomly selected cities (Urban Transportation Monitor, 1990) indicated that 71 percent believed the accuracy of their available crash data to be "good," while 26 percent rated it "reasonable," and only 3 percent found it to be "poor."

Completeness and precision mean that reports are complete and express the data with appropriate precision. A study of the crash reports used in 21 states (Wu, 1994) concluded that most of these reports do not contain the Critical Automated Data Reporting Elements (CADRE) (CADRE Task Force, 1991), and when they do, the codes adopted for the element are not completely in agreement with those recommended in the CADRE system. The results of a survey based on 35 respondents from 100 randomly selected cities (Urban Transportation Monitor, 1990) indicated that 57 percent believed the level of detail of their available crash data to be "good," while 40 percent rated it "reasonable" and only 3 percent found it to be "poor." A study of another state's experience with location coding by local communities on a special reporting program (Mounce and DeLucia, 1991) found that, out of 32 cities involved, 8 were rated as fair or poor in the completion of the collision diagram. Finally, reporting of injuries is not complete (Hopkin et al., 1993).

Precision more frequently is a problem with the collection and maintenance of roadway inventory data. The initial collection of data represents a trade-off between careful measurement and the costs of data collection. In many cases, the primary need for the data is to assist an agency in its physical inventory. Focus is placed on lane miles, widths, bridges, and other cost-sensitive items. Little or no attention is given to inventorying features such as curvature and intersection channelization.

Perhaps the clearest example of roadway inventory data needed by designers concerned with safety is data describing the roadside. Continuous descriptors for roadside slope, clear zone, guardrail, and objects are expensive to collect and maintain. Such information has limited value outside the highway safety arena. Most agencies devote few or no resources to maintaining inventories describing the roadside.

Another example of data in which precision or completeness is often lacking is traffic volume data. Again, most states maintain traffic counting programs that provide an overview of trends and that enable planning-level analyses of capacity needs, pavement loading trends, and other factors relating to programming of improvements. However, traffic volume cov-

erage data are often not of sufficient quantity or quality to provide a clear picture of safety issues.

Updating the data can be affected by the methods used. Particularly important is the need to integrate construction plans with the roadway inventory.

Consistency, especially among states, is limited. Wu concluded that there was little consistency among the states. Where common variables appeared for crash facts, the codes used for them differed widely among the states. Where American National Standards Institute (ANSI) (AAMVA, 1993) standard variables were used, the codes were not consistently adopted among the states. These results suggest that it would be inappropriate to combine data from more than one state into a single data set for regional or national analyses. Fife and Cadigan (1989) pointed to inconsistencies even among jurisdictions within a state.

Timeliness is a subject of concern among safety analysts but not one on which there is complete agreement. The results of an Urban Transportation Monitor survey (1990) indicated that only 38 percent considered the timeliness of their available crash data to be "good," while 38 percent rated it "reasonable," and 24 percent found it to be "poor." The study by Hughes et al. (1993) identified the period from the time of the crash to the completion of processing at a data center as ranging from 25 to 210 days.

A final issue of quality is the lack of adequate data from which to perform studies. This problem is a subset of the "coverage" issue, but it evolves not from a failure to capture data, but from the relative lack of crashes over a reasonable period. It is most obvious when attempting to associate roadside design and crashes involving commercial vehicles (Wolf, 1989). Rarely are there sufficient numbers of truck crashes. Exacerbating the problem is that data gathered by different states cannot be combined. The single database maintained by the federal government is incomplete and based on self-reporting; therefore, it could provide invalid data. Even for vehicular crashes, in general, attempts to study specific factors (e.g., crashes with culvert headwalls) are limited. The frequency of such crashes in any one state is often too small. The Highway Safety Information System (HSIS) operated by the FHWA has been one attempt to overcome the lack of crash data and the inability to combine those data with roadway elements. However, this system also recognizes the variability of data among collectors. As a result, HSIS studies the issue using data from one state and then attempts to replicate the findings with data from other states.

High-Hazard Locations

The more common approach today is to apply statistical principles. The first step in this process involves identifying a measure of exposure. Crash rates are then calculated on the basis of the chosen measure of exposure. A population of sites is defined as the basis for comparison with individual sites. The traditional method for computing exposure has been to use traffic volume along segments and number of entering vehicles at intersections. Rates are expressed as crashes per million vehicles or per one million entering vehicles. A mean crash rate is calculated, and those locations where rates exceed some threshold (e.g., the mean plus one standard deviation) are selected for further examination.

The validity of and confidence in any statistical exercise involving crash and exposure data are related to the quality of the exposure data. With respect to traffic flow data, a given analysis may require reasonable estimates of hourly traffic volume, turning movements, vehicle classification, and speed and speed distribution, as well as variations in these by time of day, day of the week, or even season. Such data are typically not directly available without special studies.

In a study of various statistical techniques for identifying locations, Higle and Hecht (1989) found that the traditional method of deviation from the mean has yielded many false positives. Instead, they have recommended a Bayesian approach. This summary paper reflects similar findings also reported by others, including Davis and Koutsoukos (1992) and Wright et al. (1988).

Kansas City has applied an alternative approach that employs a plot of frequency-of-occurrence to select those locations, particularly intersections, where crashes have exceeded the 85th percent cumulative level (Bhesania, 1991). The analysis is done separately for signalized and non-signalized intersections. On the other hand, Basha and Ramsey (1993) have recommended the use of "Box and Whiskers" diagrams instead of standard deviations to identify hazardous locations based on rates. The outer bounds of the box consist of the 25th and 75th percentile. Outside the box are drawn two additional lines, the "inner fence" at a position 1.5 times the difference in rates between the 25th and 75th percentile. An outer fence is drawn at 2.5 times the difference. Locations exceeding the outer fence are selected; those between the fences receive further study.

Another approach has been one of studying the network rather than single sites or types of facilities. Some of this research arises from studies indicating that there is a potential for crash migration from the treated site to untreated sites (Fawaz and Mountain, 1992). Fairlie and Taylor (1990) have applied local area traffic management to help understand the areawide potential for change. Hoque (1989) attempted to group crashes by road class and to examine those areas within individual classes that are most likely to be above the norms for that class. Because of changes in driver patterns and behavior, crashes at any one site may exceed normal as a chance result. Using spatial modeling, Loveday and Jarrett (1992) showed that, instead of one "black spot" arising from traditional exposure analyses, multiple black spots could be found within an area. Use of networks also takes into account congestion, which can affect the likelihood of crashes (Hall and Polanco de Hurtado, 1992).

Costs of Crashes as a Method for Choosing Corrective Action

The cost of crashes has been used as a measure for both selection of sites for study and choosing among alternative crash countermeasures to be employed. Generally, associated issues focus on how costs are estimated, particularly when injuries are involved. Australia has struggled with the problem because costs have been assigned according to abbreviated injury scales that may understate the "crash severity level" in terms of potential cost savings (Andreassen, 1992). This research introduced a manual on how to improve the collection and costing of data.

In another approach, Hyman (1993) recommended combining treatments for individual infrastructure management systems (e.g., for pavement upgrade or bridge repair) because treating several systems together may be more cost-effective. In a similar vein, Neuman (1988) stresses that cost-effectiveness must treat safety, design, and operation as a whole. In addition, the assumption of "safety at any cost" is no longer practical. On a broader scale are costs of congestion and air pollution, which also must be brought into any model. The costs of making improvements do not necessarily have to be based on the savings from reduced crashes. These costs also can be offset from some form of revenue such as congestion pricing (Shefer, 1994).

The selection of roadway improvements should reflect not only cost-benefit analyses, but also the implementation of newer technologies and dynamic programming to help identify how funds can be spent. Hensing (1991) encouraged the re-examination of technologies incorporated to help address costs of change. Brown et al. (1990) discuss the use of dynamic programming to assist in optimizing the costs associated with roadway safety design and improvement. With limited funds available, such programming is critical in helping select those enhancements that should result in the most cost-effective safety improvement.

The subject of what is an appropriate basis for "costing" highway crashes has been controversial. Many decision-makers are reluctant to place a value on a life saved or an injury avoided. Much of this reluctance is directly related to the lack of confidence in estimates of safety effectiveness associated with multiple alternative courses of action. Yet, whether such valuations are explicitly performed or not, decisions that imply a valuation are routinely made by agencies.

Collecting and Reporting Crash and Roadway Data

Some authors have turned to enhanced methods for collecting data through other than manual means. Hughes et al. (1993) present the most comprehensive methods for automating collection of data for the crash report. However, most states have been introducing new technologies to reduce the manual data collection by police (Parke and Kim, 1995). In addition to enhancing the quality of the data, these methods allow state safety personnel to incorporate the National Governors' Association (NGA) commercial vehicle and CADRE elements, as well as apply ANSI standards with greater assurance that they will be used correctly. Of greatest interest are bar codes and radio frequency chips that can provide more accurate data about the drivers and vehicles. None of these methods, however, enhances the data collected about the roadway. Given that typical collectors of crash data, police officers, are minimally trained in crash investigation, the value of crash data related to the roadway has been of marginal value for many applications, including highway design.

States such as Pennsylvania and Virginia use portable computers and specially instrumented vans to help update their file of roadway characteristics as described in the Site Data Book (Northwestern University Traffic Institute, 1993). Pennsylvania further incorporates updates of the roadway inventory as an integral part of road construction and maintenance. Such methods enhance the usefulness of the roadway data while decreasing collection costs.

Linked Data Sources

One of the strategies recently discussed as part of the report on the FHWA study of the costs of highway safety data has been linking data sources (Raub et al., 1995). Several strategies have been recommended on the basis of actions already taken by various states, particularly to integrate their traffic safety data with roadway data. Computers, communications, and software enhance the task. The single greatest barrier to success is "turf" in which crash reporting belongs to the safety personnel and the roadway to the engineering side. Even when the data reside within the same agency, the issues of ownership may preclude data being made readily available. The lack of availability also may be exacerbated by state privacy laws and an unwillingness by the data managers to seek methods of making data available within the constraints of those laws.

Linking databases not only makes appropriate data available to various decisionmakers when they need them, it also helps reduce the costs and enhance the accuracy of the data. There is a high "front-end" cost arising from initial development of the systems, but once they are in place, each part of the system collects and maintains only those data appropriate to that system. Other data needed by the system (e.g., driver data for crash reports) come from the linkage to the appropriate other system (e.g., driver license system).

The increasing use of data processing equipment to automate and assist in data collection was addressed previously. Once data are in an automated form, their capture to central databases is improved; however, adequate linking between those databases is not done. Deighton and Ruck (1989) addressed the importance of integrating data, including traffic, crashes, geometrics, pavement condition, maintenance,

and construction history. Rao et al. (1993) have described guidelines for executive management information systems that should be available to the decisionmakers. This work also stresses the need to integrate various databases.

Models and Computer-Aided Operations

Deterministic modeling is useful for examining options for roadway design, and microcomputers have enhanced the process by enabling the engineer to improve the complexity and sophistication of the models and to process data better; however, the literature suggests that there is very little valid modeling available for designers to use. Regardless, if a process can be modeled, generally, it can be simulated. One of the more recent applications has been integrating data for vehicle dynamics with road design. This process allows highway engineers to propose a design and then test it, particularly the geometrics, against how vehicles will behave in that design (Wade, Theodore, and Klyde, 1995; Sayers and Mink, 1995). Most of the simulation now can be performed on microcomputers as a result of the increasing power of these machines. FHWA has begun incorporating simulation in the development of an IHSDM (Sayers and Mink, 1995). In examining how the Highway Performance Monitoring System data can be used effectively, Memmott (1989) recommended the use of simulation to test the best sample sizes.

Human Factors Approach

A human factors approach has been studied (Shafer et al., 1995) to determine if nontraditional methods can be used to help improve the design of horizontal curvature. Shafer et al. measured driver mental workload (based on subjective appraisals of driver actions) as it related to curve transition and degree of horizontal curvature. By using a "vision occlusion" method (a narrowing of the vision field) to describe workload, they found a peaking during entry into the curve and lessening once the driver was within the curve itself. This finding suggested that attention needs to be given to the transition so as to reduce this increased occlusion. The method might also be appropriate for designing other roadway features.

Collision Diagramming

One of the more useful developments has been the application of computers to collision diagramming. Such diagramming can be used to help identify the types of conflicts leading to collisions and to provide safety engineers with more information about potential causes. The diagramming, particularly when linked with computer-aided drawing (CAD) systems, displays graphic representations at specific sights based on data from crash-safety databases (Nyerges and Cihon, 1989). The safety engineer can select what to display as well as to display the results for multiple locations together in order to study areawide patterns. However, not all engineers use such aides (Urban Transportation Monitor, 1990). CAD systems also can manipulate data derived from using "total stations" for assisting with the investigation of vehicle crashes (Jacobsen et al., 1992). This process allows the engineer to re-create the events of a specific crash and examine in more detail the relationship between the roadway and the events.

One problem to overcome is that, although many designers use such aids (Urban Transportation Monitor, 1990), investigation of safety and traffic operational problems is often performed by staff separate from design engineers.

Geographic Information Systems

The growth of geographic information systems (GIS) presents safety and highway design personnel with a powerful tool to locate and plot crash and roadway data together on maps (Simkowitz, 1989; Abkowitz et al., 1990). This display of spatial data allows rapid assessment of situations; this rapid assessment would not be possible using standard database and statistical packages. Instead of displaying tables containing selected crash and roadway data requiring personnel to examine multiple tables, the same data can be displayed thematically on maps (e.g., crash rates based on turning crashes along two-lane roadways). Once the maps have been interpreted, then further data analysis can help point to specific causal factors. Abkowitz showed how highway management departments could benefit from the use of GIS and how departments could integrate roadway design with GIS tools.

One of the more common approaches is to use GIS to replace traditional pin maps. This step was demonstrated by Kim et al. (1995) for Honolulu. The city is identifying the highest crash frequencies through the use of computer-drawn maps, then determining which locations can benefit from roadway changes. Australia is using GIS-based software to help capture crash records. According to Young (1992), the Australians have found considerable gains in efficiency as a result of the interface. Still another use that has been discussed is the integration of railroad grade crossing data with related safety information. The purpose is to help the U.S. DOT identify rail crossings that should be improved in order to reduce crashes (Panchanathan and Faghri, 1995). Later, this work will be coupled with artificial intelligence (AI) systems as part of a knowledge base. Another application for GIS is in helping to identify high-hazard locations for pedestrian and bicycle crashes (Raub, 1996). Raub demonstrates how the use of GIS can combine pedestrian and bicycle crash data with readily available data, such as population, and transfer the data to a map of streets in a city.

In addition to mapping the crashes, the system also can be used for infrastructure management. This allows traffic engineers to display safety information along with topographical

data and provide a single map, which can be interpreted as part of a process of safety improvements. One problem is that linear data sets were not designed to be integrated with GIS-based software.

Use of Expert Systems

Expert systems and AI are increasingly being used for traffic safety and roadway design. Systems designed in California are providing a real-time knowledge base to integrate traffic surveillance data for the purposes of monitoring freeway operations (Proesser and Ritchie, 1991). This information is used to make decisions regarding the handling of traffic using the freeways and the response to incidents. The knowledge base also provides a significant history of usage and congestion for planning.

A more important use of AI is to help test various roadway designs through the use of expert systems. AI systematically guides the designers through decisions related to costs, efficiency, and safety. One system in Great Britain allows engineers to analyze high-hazard locations and helps guide personnel in selecting appropriate responses (i.e., potential countermeasures) (Spring et al., 1991, Spring and Hummer, 1995). Another system provides guidance in the design of intersections to allow examination of the trade-offs of various design factors (Chang, 1989). Decisions on installing barriers for roadside objects also are based on the use of AI (Zhou and Layton, 1991). This type of expert system not only guides selection of barriers but helps point to changes in roadside elements that would reduce hazards more effectively than installation of barriers. Finally, Wackrill (1992) has shown how AI can be applied to identifying those elements in a roadway network that are important for efficient routing of traffic. Through the use of AI, engineers can make decisions related to traffic movements at intersections to determine how those movements assist with overall traffic flow.

Interactive Highway Safety Design Model

The FHWA is studying how to integrate what is known about the relationship between safety and design into a comprehensive IHSDM. IHSDM objectives (Harwood et al., 1994) are as follows:

- "Improve the ability of designers to consider safety in the highway design process.
- "Provide improved quantitative relationships between geometric design elements and accidents for use by designers.
- "Automate the consideration of safety in the highway design process . . ."

The IHSDM is intended to be used by designers to evaluate the relative safety of various geometrics for specific highway improvement projects. It focuses on just one, albeit central, aspect of highway design. The model will be constructed in six separate modules as follows:

- *A crash predictive module:* This is the core module and the one recognized as presenting the greatest challenge. It would involve models to estimate the expected number and severity of crashes for a given geometric design.
- *A design policy review module:* This is essentially to monitor the design vis-a-vis controlling standards.
- *A design consistency review module:* The developing concepts of design consistency would be reflected, along with the application of driver expectancy rules.
- *A benefit cost module:* This module is intended only for trade-offs to be made within a project when considering alternative designs intended to enhance safety.
- *A driver/vehicle dynamics module:* This would be a simulation and would reflect both driver control and vehicle dynamics in a moving vehicle.
- *A graphics module:* This module would facilitate the presentation of design and other information in a format to facilitate designer understanding and absorption of information.

Aspects of simulation, deterministic modeling, and AI, of the type discussed in the sections above, are recommended for this system of modules. Although use of design consistency and driver expectancy are discussed, the context and discussion seem to exclude human factors principles. The desire to arrive at highly quantitative methods may be a partial explanation.

The major point of interface between the IHSDM and Project 17-12, therefore, is seen as the delivery of useful data for the development of the underlying models and for the operation of the model for any particular project. Key features of the IHSDM plan that relate strongly to the project include the following:

- Use of consistent collision definitions in safety research,
- Coordination by a central data quality assurance contractor, and
- Development of user-friendly software designed for effective use in the operating environment of a highway capacity agency.

Post Hoc Evaluation of the Effectiveness of Design Improvements

Different approaches to testing the effectiveness of road design related to safety have been employed. A traditional approach has been a before-after comparison of crashes. An example of this approach is shown in the references in Datta's (1991) paper addressing the relative effectiveness of newly installed traffic signals in reducing head-on, left-turn crashes. Many of the previous studies of safety effects suffer from a

problem common to before-and-after studies—regression to the mean. This is especially true when using short-period count data. For example, a particularly bad location is likely to improve regardless of intervention. When examining changes in frequency or rates, some authors suggest the need to incorporate several years' worth of data from a before and an after period (Benekohal, 1991). However, waiting an appropriate time to collect "after" data may not be feasible given the political perspective under which corrective action generally is taken.

An approach appearing more frequently is to use statistical estimates to forecast the number of crashes expected without countermeasures and then to test the results against the estimates (Quaye and Hauer, 1995). One reason for estimating crashes is to examine effects against a network of roads. The "migration" of traffic crashes has been the subject of significant controversy and has resulted in the questioning of the validity of before and after measures at specific sites (Fawaz and Mountain, 1992; Loveday and Jarrett, 1992). Significant related work has been done on the description of the mathematical properties of traffic crashes (e.g., the Nicholson and Wong [1992] investigation into the likely fit of a Poisson distribution over other statistical tests). This work on mathematical theory has provided a better basis for using statistical methodology.

Another traditional approach has been to assign costs to both the treatment and crashes. A given treatment cost of "x" dollars will produce "y" dollars reduction in the costs of crashes. This result then becomes a measure of cost-effectiveness. The National Safety Council often uses this approach, which depends on the costs to society of crashes (based on criteria such as severity of injury) and then compares the costs incurred before and after treatment with the costs of implementing the treatment. However, the method suffers from two problems. First is the use of short-term counts to provide crash data. The second is an uncertainty artificiality in assigning costs for injury, particularly for indirect (societal) losses.

Other Issues and Efforts

Much of the recent work related to enhancing safety as part of roadway design has involved better integration of automated methods and enhanced collection of safety data. Some attention, however, is still being paid to other approaches. One approach has been to concentrate more on combining systems. Wallen (1993) indicates a need to incorporate human factors and road user needs into the training of engineers. Too often, the engineer has adhered to the dogma of standards without considering the human factor. In some cases, courts have found liability when standards have been maintained in a situation where driver behavior or perceptions were contrary.

In addition, there is a need to consider the "system" of driver, vehicle, and roadway (Ranney and Simmons, 1993). Ranney and Simmons address the issues raised by Wallen and consider such issues as congestion and the relationship of design to congestion and to safety. In fact, a congested road may be safer, but it will also incur large societal costs because of the congestion.

A large body of literature is developing as the result of increasing numbers of cases filed and successfully heard against highway departments for alleged failures in roadway design, construction, and operation. Gittings (1987 and 1991) thoroughly explored the issues for the State of Pennsylvania.

One unfortunate result of the increased exposure of agencies to tort claims is a growing tendency to adhere to standards regardless of the appropriateness of the resulting design. Many tort losses focus on a condition that is demonstrably "substandard," but which has not been treated or improved. A typical design engineer's reaction to tort concerns is to design to full standards "at all costs." Contributing to this approach is the lack of available, quality information describing the safety trade-offs among various alternatives, some of which may involve a nominally substandard design.

Other states have begun extensive work in reviewing risk management. Culkin et al. (1988) indicated the need to include all disciplines in analyzing potential risk, including design, construction, and maintenance personnel. Each crash should be reviewed by highway engineers—as soon as the data are available—in order to highlight potential roadway-related contributions. The use of traditional tools such as decision analysis to assist with interpreting potential liability is one method of helping interpret the crash data (Kulkarni et al., 1993).

Design Process

How agencies implement highway improvements is not an item of frequent study; however, *TRB Special Report 214* documented the practices of several states and summarized them with regard to the federal resurfacing, restoration, and rehabilitation (RRR) program. *TRB Special Report 214* defined a generalized process that has six core steps:

1. Candidate projects identified,
2. Federal-aid projects selected,
3. Design concept completed,
4. Design exceptions requested,
5. Design exceptions approved or denied, and
6. Final plans and specifications completed.

In addition to these major activities, a series of supporting activities are noted, including the following:

- Field reviews by the FHWA, central state office, and design engineers;
- FHWA and central state office reviews and approvals;
- FHWA formal and informal guidance;

- Review by state traffic and safety specialists;
- Development of justifications for possible design exceptions;
- Reviews of crash data by FHWA representatives, state specialists, and design engineers;
- Development of a pre-design report;
- Conduct of safety cost-effectiveness analysis; and
- Post-construction safety evaluation by the state agency.

A two-tiered process exists where projects can be funded without federal participation. The state-funded process usually is less involved. Most state districts receive reports of crashes in their jurisdiction and are expected to review them in order to identify possible problems. However, only a few states even use high-hazard location analyses to identify candidates for RRR projects. Most of these projects are selected on the basis of the need for pavement improvements. Thus, only a small number of RRR projects initially would have been identified on the basis of concerns for safety. However, on the basis of the states contacted by the research team, an increasing number are requiring that every project include a formal review of crash experience, regardless of the basis for initial identification of the site. Therefore, even pavement improvement projects would include consideration of minor site improvements to enhance safety.

Conclusions

The literature and the experience of the research team indicate that, despite extensive research in the area, there is too little available that establishes a valid relationship between geometric elements and highway safety. Most efforts to relate the two have reflected the results of studies with inappropriate statistical procedures and without reference to the high variability associated with the relationships derived. As a result, designers and those who develop design guides and standards must rely on their own judgment to a great degree. The comprehensive reviews of the research, which were discussed briefly in this document, provide an overview for establishing judgments about the relationships that have been found. Moreover, lack of good data (and resulting lack of safety relationships) results in safety having less of an effect on decision-making.

CONTACT SURVEY AND RESPONSES

In addition to the literature review, the research team undertook a survey of current practices with respect to the use of safety information. A brief survey was sent to the Governor's Highway Safety Representative of each state. The primary objective of the survey was to obtain names and numbers for further contact on details, as work proceeded on the project. However, the opportunity was taken to ask a few, very general, questions to provide an update on the team's perspective regarding state practices. A total of 33 states responded.

Appendix C contains a complete report of the responses along with a copy of the survey. This section summarizes these findings.

Crash Reporting

The first question was designed to gain a general idea of the extent to which three national standards for traffic crash reporting (i.e., ANSI, NGA, and CADRE) were being used. The particular ANSI standard was not specified, because the objective was not to complicate the survey, but to get general perspectives. Very few of the states indicated complete adoption of any of these standards. About an equal number indicated either partial adoption or none. The relatively large number of states indicating no compliance, even though these are not newly published standards, was unexpected.

Roadway Inventory

Eleven of the 33 states responding indicated that they were not able to link their roadway inventory data with PCR files. Although the rest indicated that this was possible, some qualified that capability. Some states have links for only a few roadway classes. One state indicated that although such a link was technically feasible, it was not allowed for other reasons. Other states indicated that although linking was not currently possible, they were experimenting with creating this capability. Again, the comments suggested that the primary motivation was SMS requirements.

Technologies Used to Enter Data

Table 2 summarizes the responses on use or testing of technologies to improve collection of data. Computer-based tools are being used, but not as widely as expected.

In general, the "other" choice was used by respondents to make further comments, rather than to indicate other technologies in use or under testing. One state indicated that state personnel were using forms-generating software which, presumably, other states may have included under the "personal computer" choice.

Application of New Technologies

States appear less involved in using or experimenting with new technologies for data management than they do for data collection. Table 3 summarizes results from this part of the survey. The use of scannable forms seems to be increasing rapidly, but the upgrading of outdated database management systems seems to be lagging. The use or testing of aerial imaging was more prevalent than expected and should be fur-

TABLE 2 Reported use or testing of technologies for data collection

Type of Technology	Number of States Indicating Use or Testing
Portable Computers	18
Global Positioning Systems (GPS)	16
Instrumented Vehicle for Inventory	17
Geographic Information System (GIS)	19
GIS and Image Recognition from Videologs	9
Bar Code, Mag. Stripe, or Smart Cards	8
Laser-based Measurement	9
Other	5
No Items Selected	2

33 states responded to the survey

ther explored in direct contacts. In addition to further explanatory comments, the other choice included a reminder that scannable forms can be implemented as part of a document imaging system.

States seem to be only starting to address the application of technologies to facilitate the use of safety data. As shown in Table 4, less than 40 percent of the respondents indicated use or testing of GIS. One-third of the respondents, however, indicated that they were working on linkage with medical data sources. Although only eight states were using graphical interfaces for end users, this was a greater frequency than expected.

Finally, the survey identified 218 contacts for nine classes of users or areas of responsibility. Obtaining such a wide range of contacts proved the value of such a contact survey. The nine classes are as follows:

- County Agency Design User,
- Data Collection,
- Data Management,
- PCR Design,
- Regional Agency Design User,

TABLE 3 Reported use or testing of technologies for data management

Type of Technology	Number of States Using or Testing
Scannable Forms (OCR or OMR)	10
Relational, Object-Oriented or Distributed Data Bases	10
Aerial Imaging of Roadways	5
Other	4
No Items Selected	3

33 states responded to the survey

TABLE 4 Reported use of testing of technologies for facilitating use of safety data

Type of Technology	Number of States Indicating Use or Testing
Linkage Between Crash Reports and Medical Data	12
Geographic Information Systems	15
Direct End-User Access Using Graphical Interfaces	8
Data Analysis or Modeling Tools	11
Decision-Support Systems	10
Other	2
No Items Selected	1

33 states responded to the survey

- Roadway Inventory,
- State Agency Design User, and
- County Agency Design User.

THE PROCESS OF ROADWAY DESIGN

An understanding of the roadway design process is central to any discussion of improvements to the use of safety data in highway design. Although transportation and highway agencies differ in terms of their organizations and structures, their general approach to the design process is similar.

Figure 3 depicts the highway planning and design process. Three levels of activity are shown:

1. System (Planning),
2. Project (Design), and
3. System Management.

Within each of these levels of activity, similar types of decisions are being made that involve highway safety considerations. However, the perspective from which the decisions are made at each of the levels and the information needed to support those decisions vary.

Designers need two types of safety information:

1. Information to identify the existence and nature of safety problems at a site, and
2. Information to predict the consequent safety effect of a design decision.

A "design decision" is any decision made while completing the design. Therefore, a design decision can be a high-level decisionmaker committing construction funds to one project versus another; a project designer selecting the size and location of a channelizing island and its three-dimensional alignment; or a researcher recommending a change in design policy.

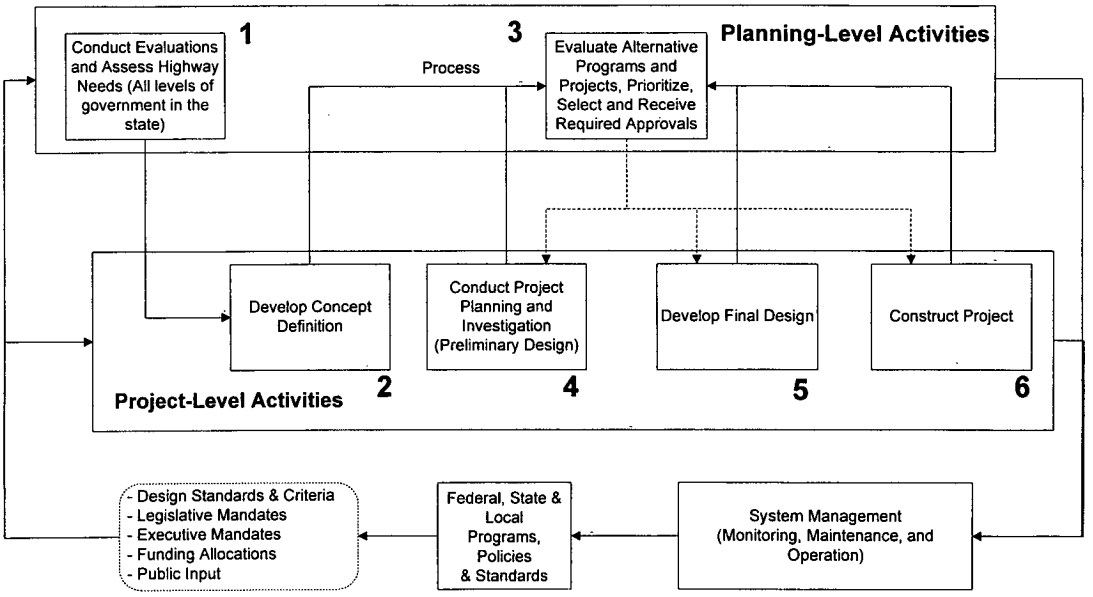

Figure 3. Schematic of the highway planning and design process.

Current tools and techniques are more advanced for the decisionmaker than for the project designer. Highway engineers have very limited ability to predict the safety effect of a design decision. As a result, they often must rely on surrogates for measures of safety or deal with safety in more subjective or qualitative terms.

Problem Identification

The first type of information helps the designer identify possible problem locations and define the safety problem at each location. General problem identification is done in stage 1 of the design process (the stages refer to the numbers shown in Figure 3). In addition to problem identification, during stage 1, analysts may need information to help them ensure that effective design strategies exist to deal with the identified problem(s). Problem identification may not involve predicting the effect of those alternative countermeasures; however, it provides additional bases for defining projects to be studied.

Once individual projects are established, the designer must understand the probable factors producing the safety problem. This understanding can provide a basis for identifying alternative design modifications that should be tested. Identifying alternative designs is done in stages 2 and 4.

Predicting Safety Impacts

The specifics of a design strategy are implemented in the context of design policy as detailed in design stages 4 and 5. In stages 2 and 4, the designer considers alternative designs. In stages 4 and 5, the designer focuses on optimizing the implementation of a selected design. Thus, during the later stages, it would be helpful for the designer to be able to predict the effect of design decisions on highway safety. The ability to make such predictions would improve the basis for deciding on alternative designs for highway elements or combinations of elements.

The Role of Design Policy

Design policy for a given state typically reflects both national and local policy. The specific set of applicable standards depends on the project; however, a basic structure is common to most design guides. The policies are established by committees representing the design community. Many elements of a design policy reflect principles of creating a safe design. This is usually accomplished by using models of vehicle dynamics and, to a lesser extent, human factors considerations. In many cases, the professional judgment of those establishing the policy is relied on.

Design policies and standards have evolved over time. Many of the current standards, design "models" and assumptions, and design values have been essentially unchanged for 30 years or more. Most of the original design policy assumptions in early AASHTO policies reflected pure judgment or cursory reference to safety. The lack of good safety data at the time the policies were formulated precluded sophisticated or in-depth evaluations of design values. Rational models (e.g., the AASHTO stopping sight distance model, involving a 6-in object as a critical obstruction) from which design values were calculated had a theoretical safety input, but one not clearly linked to actual safety performance.

The profession has tended to retain a design standard or value until there is a demonstrated need for or perceived value to changing it. Because standards are critical to the design process, historically, there has been a reluctance to make frequent and/or substantive changes to design policies or standard values. As a result, to this day, many important design values and models have little or no demonstrable link to quantifiable measures of safety.

Direct application of relationships between design elements and the potential for crashes has not been made because generally such relationships have not been available. Therefore, information needed to predict safety impacts is limited and an area of need. The ability to relate safety and design would allow for improved design policies to be established and would provide the project designer with tools for making more informed decisions about alternative treatments at a site.

Current design policies generally have a structure and content that will result in four types of design decisions being made on a project. These are as follows:

1. **Basic policy.** Basic relationships and some of the independent variables for them are established by policy to apply across all types of projects. Decisions about basic policy usually are made by a committee of designers and published as part of the state design guide. The condition is changeable only by receiving approval of a design exception.

   Basic policy can range from general policies to specific design criteria and standards. An example of the former would be the policy of some Midwestern states to preclude consideration of signal-controlled intersections on all multilane rural highways. An example of the latter would be the establishment of a maximum superelevation policy for a given state, such as a policy to govern the design of all horizontal curvature by that state's designers.
2. **Project policy.** Some independent variables for design relationships are established as design policy for each project and may vary among projects. A decision is made at the outset of a project in which the designer establishes the policy to be applied to the project. Selection of a design speed, design vehicle, or type of roadway are examples of project-level decisions that afford the designer some discretion. Maximum grade and maximum superelevation are examples of key variables (or sets of variables) that will vary from one project to another. Design policies, however, usually allow only restricted choices.
3. **Design constraints.** There are many design elements or features for which minimum or maximum values have been established by policy, but for which the designer may use values above or below, respectively, the established limit. Radius of curve and grade are examples of this. Exceeding the established limit for any particular design element also requires receiving approval of a design exception.
4. **No design constraints.** Design elements exist for which there are no specific policies established, and designers must select what they consider to be appropriate for the project. There are fewer of these today than in the recent past. Type of intersection channelization is one example; however, individual state policies are tending to limit choices where they do not exist now.

Stages of the Design

During each stage of the design, a series of questions is posed. These questions are summarized below. They apply to each of the six stages shown in Figure 3.

Stage 1. Conduct evaluations and assess highway needs.

These questions are to be answered in a general way at this stage. Decisions do not commit the agency to action, other than further study. Therefore, the information on which the decision is based is aggregate.

1.0 *Which parts of the system need to be studied further toward improvement?*

1. Which parts of the system need improvement?
2. What is the nature of the need for improvement at each part of the system identified?

Stage 2. Develop concept definition.

At this step, each project is being considered individually, rather than as one of a group of projects, and the decision commits the agency to further use of its resources for planning and design. The needs of the site are considered in more detail than during the first step, but the information is still rather general and aggregate.

The answers regarding the actions need neither be very specific, nor need the estimate of costs be more than preliminary. The expected benefits may not all need to be stated in quantitative terms, and, if they are, may also be preliminary estimates. Some highway needs studies (Stage 1) may also include these questions in a very preliminary analysis. Recent legislation may require that a project go through a major investment study.

2.0 *What type of improvement, if any, should be proposed for further study?*

1. What is the specific nature of the needs at the site (this is a closer look at the specific site than may have been done in Stage 1)?
2. What is the nature of alternative actions needed to meet the needs of the site?
3. What is the order-of-magnitude cost to meet the needs, using the identified actions?

4. What are the expected effects of carrying out those actions?
5. Is there a public transport alternative to the proposed project that will meet the travel demands, or meet the identified needs, at least as well as the proposed highway construction or reconstruction?

Stage 3. Evaluate programs and projects and prioritize, select, and receive required approvals.

Evaluation of the range of possible investments in the system may be carried out more than once in the design process. After each step is completed at the project level, the results have to be reviewed at a higher level and approved for the next step. In each of these cases, the project is considered in the broader context of the needs in the system and the resources available to meet those needs.

The basic decision is that the level of further investment being committed to when entering project planning and investigation is less than that being committed to when entering final design. Both of these activities, however, are much less of an investment than what results from the decision to proceed with construction. Generally, after the project planning and investigation (preliminary design) are completed, if the decision is made to proceed with a project, it is rarely eliminated from the implementation program at later stages. Thus, the decisions made when evaluating and programming projects after the preliminary design step in the process take on an added importance.

3.0 *Should further investment be made in this project?*

1. Which locations should be scheduled for further implementation of the identified improvements?
2. When should the identified improvement be implemented?

Stage 4. Conduct project planning and investigation (preliminary design).

This step is where the needs of the site are addressed in detail.

4.0 *Which of the alternative means for meeting the identified needs of the site should be recommended for implementation?*

1. What are the applicable specific objectives for site and system operation?
2. What are the specific needs of the site (a revisiting, in greater detail, of the question asked at each step)?
3. What alternative means exist for meeting those needs (this is essentially the preliminary design task and is discussed further below)?
4. What is the anticipated effect of each alternative on achieving the objectives established for the site improvement?
5. What are the anticipated costs associated with each alternative?
6. What is the relative cost-effectiveness for each site?

In addition, especially when examining alternative means, a series of choices exists. Generally, a set of decisions regarding these choices constitutes an alternative design. The number and variation of alternatives often are determined by the nature of the project, agency, and designer. If it were possible to immediately (in real time) estimate and consider all the impacts of concern when making all of the above design decisions, it might not be necessary to generate a set of alternatives. An optimum design might be derived directly (e.g., through simultaneous solution of a multidimensional set of relationships or through interactive design models, by trial-and-error, using some automated expert systems to guide the successive trials to ensure that a global optimum is being approached). The ability to predict effects for a wide variety of measures of effectiveness (MOE), however, is severely limited, making such an approach infeasible. The approach taken, instead, is to generate a set of alternatives considered representative of the range of feasible possibilities. These may then be subjected to an assessment and selection process to arrive at the recommended scheme.

- Choices among alternative design policies that should be applicable to the project (e.g., class of facility, design speed, design vehicle, or design year),
- Choices among possible values to use for individual design elements (e.g., degree of curve, superelevation, length of tangent, or location of ramp diverge-point), and
- Choices among alternative combinations of design elements (e.g., interchange type, use and manner of grade separation, or relative placement of horizontal and vertical curves).

Stage 5. Develop final design.

The preparation of contract plans and specifications generally involves the detailing of the preliminary design developed in Stage 4. In rare cases, a preliminary design will be significantly changed during the final design process. Examples include changing the type of interchange or realignment of part of the facility.

Furthermore, as the design is detailed, it is developed with greater accuracy and precision than for preliminary design. This may result in some changes that are considered minor but that can affect the operation of the facility significantly. Examples include the relocation of a ramp merge- or diverge-point, addition of an access point, or modification of channelization. In such cases, the questions to be answered or decisions to be made are of the same type as listed in Stage 4, above.

5.0 *Which of the alternative means for implementing the details of the design should be used?*

1. Choices among possible values to use for individual design elements (e.g., cross-slope and superelevation transitions, length of transition curves, and steepness of roadside slopes).
2. Location and type of walls, roadside barriers, attenuation devices, signing and marking, and other appurtenances.
3. Choice among alternative plans for management of traffic under construction.

Stage 6. Construct project.

If the project is constructed in strict accordance with the final design, there would be no decisions required that would further affect the resulting safety of the facility. Often small changes to the design are required; these decisions are reached in the field by the engineers in charge. These decisions generally are not of the type that will significantly affect the safety of the resulting operation. Any decisions likely to significantly affect highway safety will require the same information as that for preliminary and final design.

The implementation of a traffic controls plan is an important part of this stage. It must be done in accordance with the established plan.

System Management

In addition to the six stages, system management activities are constantly occurring and will involve the project once it is completed. Operation at the site should be monitored for operational and crash experience in order to determine if unanticipated problems have occurred (e.g., driver confusion created by channelization or the traffic attracted is much greater than anticipated).

The establishment of programs, police, and design guides should be based, in part, on information derived from system monitoring. Safety data are needed to help establish design policies and, potentially, for use in models that are used to predict the effects of design modifications. Legislative and executive mandates on programs and policies should also reflect safety considerations by using information and relationships established from system monitoring.

At this level, important and far-reaching decisions are made that can significantly affect the safety of operation in the entire system. Decision making at this level, however, often does not involve designers, with the general exception of establishment of design policies and standards. Indeed, perhaps the greatest long-term benefit of improved safety information for design is in its expected effects on the geometric design criteria and standards that each state uses.

SAFETY DATA NEEDED FOR PLANNING, DESIGN, AND RELATED RESEARCH

Classes of Data

Crash reporting, roadway inventory, and other sources have available many elements that provide safety data for roadway design. Some of the data apply to planning; others will assist the design; and some will assist the researcher.

Appendix D provides a table of data elements (in the form of a data dictionary) comprising descriptions of data types, dimensional requirements, and means of collecting the data. The data dictionary identifies those data items that the research team deems important.

The differences between the proposed requirements and current practice are evident. Many of the elements are not collected currently. If they are collected, they are not maintained in digital format or in easily accessed files. More important, the level of detail and accuracy, completeness, and coverage preclude using many of the elements for traffic safety analyses. Although extensive, not all of the elements may be critical.

The following is a brief overview of the data requirements outlined in Appendix D. The application of proven and emerging technologies offers an opportunity to obtain more and higher quality data than are currently collected.

Crash Data

Precise crash data are needed but are frequently not available. A key difficulty is defining what "location" means. For most crashes, the first harmful event may suffice, but this is not always true. Even if the location definition could be clarified, collecting a descriptor of the location with sufficient reliability and precision to be of use to the designer often is not done. Those collecting the data, the crash investigators, often are not trained or do not have the time to collect the harmful events. Measurements often are not precise, even to a variation of plus or minus 10 m—a dimension that may have important meaning to a designer if not a police officer. Increased use of corrected global positioning systems (GPS) receivers coupled with computerized reporting will significantly improve the measuring of locations (given that the locations are identified first).

What the crash investigator collects best are data that are useful in case management (i.e., names of those involved, time of day, day of the week, and general descriptors of the crash). Information outside of those needs, which generally pertain to enforcement or court action, is obtained as the investigator has time and is trained. Even what would appear as simple, observable facts, such as current roadway surface or condition of a traffic signal, can often be missing. Manner of collision and direction of travel, unless the crash has resulted in fatalities or extremely severe injuries, are collected only because the supervisor requests it. Because no means exist

to verify the quality of the data collected, any entry generally will be accepted at the first, and most important, editing level, the supervisor. Use of vehicle "black boxes" and trained personnel, not necessarily police, can improve the data collected.

Finally, as noted in other papers, few crashes are recorded in a directly accessible fashion. As many as 50 percent of crashes may go unreported, or at least unreported to a central database. Using police service logs for crash identification, coupled with better crash location identification, is an important potential solution.

Traffic Operations Data

Traffic volume is the most important variable contributing to the frequency of crashes. Particularly critical data include intersection turning movements and vehicle classification data. Such data usually are either not maintained or are not counted at sufficient locations and, therefore, are useful only for systemwide safety information needs. With the advent of widespread computerized traffic signal system networks that collect and process traffic volume data for operations, such data should be available for use in the safety system. All that is necessary is the establishment of links to enable capture of this database.

Other safety-related operations data that are critical include measures of speed. Such data generally are not collected and maintained, but they would be essential to designers.

Geometric Design Data

Data on many geometric elements are currently not available or are of poor quality. The most critical include descriptions of the roadside, vertical alignment, and intersections.

Roadside Data

An overriding concern is that roadside data rarely are maintained in an automated form. Slope, clear zone, types of obstacles, and their location, however, often are available, using photologs or videologs. In recent years, sophisticated instrumented vehicle systems incorporating measures of cross section, roadside, and other features demonstrate the feasibility of obtaining roadside data.

Also of importance is information on location, design, and characteristics of roadside barriers. In the future, with the use of GIS databases and more sophisticated automated vehicle inventorying systems, capturing and maintaining roadside and barrier data should be viable and cost-effective. Also, automatic input of computer-aided drafting and design (CADD) data, as well as maintenance records involving crash cushion repair, guardrail repair, and so forth, would greatly enhance understanding and design of the roadside.

Intersections are among the most important features affecting safety. Currently, little information is available for designers other than location. Items of importance that should be maintained in a safety-sensitive database include the traffic control, presence of channelization (i.e., right- and left-turn lanes), intersection sight distance, and traffic volumes and movements through the intersection.

With respect to both horizontal and vertical alignment, horizontal data generally are available and, therefore, more readily obtainable. Vertical alignment and, in particular, the resultant stopping distances and passing sight distances are, for the most part, not available under current data systems. Input of CADD data, the use of IHSDM to generate sight distance profiles for input to databases, and the automated vehicle inventory systems should provide the means to obtain these data in the future.

Traffic Control Data

Information on traffic control, signing, pavement markings, signal systems, and regulations is crucial and should include presence, adherence to prevailing criteria, and condition and reflectivity. In the future, automated vehicle inventory systems and GIS-based sign inventories linked to the geometric data will provide more complete, integrated data for designers.

Issues Associated with the Quality and Use of Safety Data

"Despite the widely acknowledged importance of safety in highway design, the scientific and engineering research necessary to answer these questions [i.e., about the relationship between roadway geometry and safety] is quite limited, sometimes contradictory, and often insufficient to establish firm and scientifically defensible numerical relationships."[2] (Bracketed material added).

"So the standards committee has nothing tangible to go on. But roads have to be built and engineers are reared to be doers, not doubters. Therefore, considerations other than safety have to shape the decision. Naturally, at the end of the day a decision is made."[3]

"I think most designers strive for mild grades, large radii, and long sight distances. However, inasmuch as these cost money to attain and there is only vague guidance on their safety benefits, the cost-benefit comparison cannot be determined. Thus, whereas the concern with safety of those involved is genuine, the safety related activities of highway geometric designers are akin to a ritual. Engineers design

[2] Transportation Research Board, "Designing Safer Roads," *Special Report 214*, Transportation Research Board, National Research Council, Washington, D.C., 1987, p.76.

[3] Ezra Hauer, *A Case for Science-Based Road Safety Design and Management*, in *Highway Safety: At the Crossroads*, Proceeding of a Conference March 28–30, 1988, Edited by Robert E. Stammer, American Society of Civil Engineers, pp. 241–267.

roads either without knowledge of what affects safety and how, or without using such knowledge of it explicitly."[4]

Although these quotes are based on work published in the late 1980s, conditions have not changed much. Consider the conclusions of the team working on the development of the IHSDM: ". . . this plan recommends that new safety relationships be developed for use in the IHSDM accident predictive model."[5]

The question can be asked: How are improved models to predict safety impacts going to be produced, if they have not been produced until now? The authors of the IHSDM concept report apparently decided that they must proceed on what is essentially "faith" that "with improved safety data bases and analysis techniques, it will be possible to develop valid statistical relationships that quantify the incremental effects of geometric features on safety. However, it should be recognized that major improvements in the quality and completeness of accident data may be required to make improved statistical relationships feasible."[6]

It can be concluded, therefore, that the importance of quality data and a system for their analysis are keys to progress in improving safety through highway design. Another key is the delivery of quality information to decisionmakers. The following questions, therefore, arise:

- What are the current issues in obtaining quality safety data?
- What opportunities exist to improve current safety information systems?
- How can improved safety information systems be integrated into the design process so as to have a positive effect on the safety of highway designs?

A set of issues were identified as preventing the desired type and quality of safety information being available to, or used by, the decisionmaker when it is needed to support decisions during the design process. These were derived from the same set of early project activities cited above. The issues are listed in Appendix D, covering the following:

- Collection and management of roadway data,
- Collection and management of traffic and control data,
- Collection of data for traffic crash history,
- Management of data for traffic crash history,
- Collection and management of non-traditional sources of safety data, and
- Use of highway safety data.

The issues addressed cover the technical and organizational/institutional aspects of the systems. For purposes of discussion, issues are grouped by source. Traditional sources, which include crash data, roadway inventory, and vehicle counts, are the source of almost all safety data obtained. Another set of sources, considered nontraditional, are rarely used. For example, a substantial number of complaints are received by highway agencies. These complaints can and often do represent real or perceived dangers. Yet, complaints rarely are collected and made available as a source of information for designers.

Issues Related to Traditional Sources of Safety Data

Collection of quality crash data often suffers from lack of attention, especially within urban agencies. This lack of attention results from pressures on these agencies to focus most of their declining resources on crime prevention and related activities. Most state highway patrols (which generally produce quality crash reports), on the other hand, are focused on providing traffic services rather than crime prevention. Even with these agencies, a problem arises from the conflicting roles of the law enforcement officer at the scene of a crash. The result is that many law enforcement agencies do not provide the training and incentives to perform adequately as crash investigators, except in serious cases for which they are likely to be providing court testimony. In addition, the crash reporting function has only recently begun to adopt the use of technologies that can help. Investigators are often asked to make judgments that they are not trained to make or to supply data that should be available elsewhere (i.e., duplication of effort). The result is that data in standard PCRs are often inaccurate and incomplete. In addition, crash reporting may not be done consistently across jurisdictions and over time.

Crash data management also affects the quality of data for safety analyses. Duplication of data handling, outdated data management systems, and lack of system compatibility to allow file linkage all contribute to delays, inaccuracies, and inefficiencies. The data management effort usually suffers from insufficient quality assurance.

Users or potential users of crash data for safety analyses find the data difficult to access. Computer-generated tabulations are often of limited use because of significant errors resulting from the coding. The location of the crash is the single most difficult problem for project-level work. The location of the crash is often either missing or wrong. Users of crash data for project-level analysis frequently want access to a copy of the original report, so that they can interpret and recode each one. Users learn through experience to distrust location codes, thus minimizing the utility of even "correct" information. Finally, even when good quality data are available, many users do not have adequate training in how to conduct analyses.

The problems and apparent resolution for geometric and traffic data are similar to those associated with the crash

[4] Ibid.
[5] D. W. Harwood et. al., "Conceptual Plan for an Interactive Highway Safety Design Model," *FHWA Report FHWA-RD-93-122*, Draft Final Report, February 1994.
[6] *Ibid.*

data. Currently, geometric and traffic data are insufficient and data that do exist are relatively inadequate. These problems stem from the limitations of current data collection technologies, a lack of emphasis on meeting safety needs in the acquisition and maintenance of data, and the lack of links to other databases.

Another important problem affects the quality and utility of safety-related geometric data. Many key features of the roadway are not stable over time, but change. Changes can occur as a result of normal "wear and tear" (e.g., signs and pavement markings and pavement skid resistance that deteriorate), maintenance activities (e.g., guardrail placement and paving of shoulder) or major rehabilitation or reconstruction (e.g., widening and intersection channelization). Capturing the above changes as they occur is generally not possible under current procedures and technologies. As a result, any given geometric data file may contain a significant amount of inaccurate or outdated information.

Geometric databases are, for the most, part constructed from manual or video field inventories. The data are collected in a paper-based manner, with labor required to gather and code the data. In many cases, the data recovered are primarily intended to support programming efforts. As such, the types of data that tend to be recovered are categorical or focus on features such as the physical condition (e.g., pavement inventory and bridge sufficiency data). Many data important to designers are simply not collected, often because such data are difficult or time consuming to collect. The best example of this is roadside data, including slope, clear zone, and guardrail and other barrier presence and design. Safety researchers understand that the quality of the roadside is among the most important safety-related features on two-lane rural highways. Yet, few agencies even attempt to collect, maintain, and evaluate roadside condition data.

Until recently, most design agencies constructed highways from hand-drawn plans. Retention of the design data in a geometric data file required the agency to manually transfer the plan data to a coded format for input to the computerized geometric database. Some agencies have done a better job than others at updating their data from construction plans. In all cases, the exercise itself has been time consuming and labor intensive.

A related problem is the lack of systematic retention of historic geometric data. Once changes to a geometric database are made, the previous condition or characteristic is not retained for reference. The lack of routine historical geometric data limits the ability of agency staff to investigate the actual, long-term effectiveness of changes to particular locations. It also limits the ability of researchers to perform safety studies.

Similar problems exist with respect to collection and maintenance of traffic volume and speed data. Most states maintain a program of traffic counting, including vehicle classification and hourly distribution throughout the year at selected locations. Mobile counting and permanent automatic traffic recorder counting stations are established. A select number of these may be configured to obtain speed data. Again, for the most part, the locations are established to support programming efforts, including overall system monitoring. For any one location, however, it is likely that a nearby traffic count does not exist. This limits the ability to understand safety at that location.

Issues Related to Data From Nontraditional Sources

In order to address needs for data other than those arising from the traditional sources, design personnel in several states throughout the country were contacted. They were asked to indicate what kinds of information, other than crash records and the roadway inventory, would be of value and where the source would lie. Responses varied from those indicating that they would be happy to receive timely and accurate crash reports to those who visualized the availability of information from a wide variety of sources—many of which are not now available.

Personnel commonly expressed belief that data sources (other than those crash-related) can be used to identify safety issues before such issues result in crashes. Moreover, because less than 50 percent of all crashes may be reported formally to state databases, these other sources can serve as a surrogate for crash reporting. Sources for data other than PCRs include the following:

- Pavement and bridge management systems,
- Maintenance information systems,
- Reports of crashes to the police,
- Citizen and police reports of roadway conditions, and
- Photolog and videos.

Skid numbers from the pavement management system are particularly valuable. Provided the skid numbers are maintained on a 3- to 5-year basis and only the extreme lows accessed, these numbers can indicate locations that may benefit from reconstruction. However, skid numbers rarely are gathered regularly. The more likely case is to wait for a series of crashes in which road surface appears as a contributory factor, then go to the field to measure the pavement friction. Other elements, such as pavement condition and markings, rarely are captured, but the information can be valuable in identifying areas that may later have safety-related problems.

Data regarding segments of the roadway that require frequent maintenance come from a maintenance system. For example, the frequent replacement of signs may represent a roadway design problem even though crash reports do not reflect a problem. Collecting these data other than through paper systems has proven to be difficult.

Police agencies receive more reports of crashes than they process. In many cases, the police will not respond; the

report more or less serves as an official notice for insurance purposes. Even where the police respond, they may not take action because damage does not exceed the state reporting threshold. Yet, the police retain a record of having provided a service. A database containing sufficient data about the crash and its location, regardless of subsequent police action, would be valuable in highlighting those locations that may be "dangerous," but do not yet show up in high-hazard analyses.

Reports of roadway defects from citizens and police provide a base from which potential dangerous situations can be ascertained. Such a system requires relatively precise location and description of the situation. Public input is very important because it provides "eyes" that otherwise are not available to the highway personnel. However, as one state engineer indicated, such data can prove to be a liability in that they could be used to "represent notice of a defect" in tort action.

Automated interpretation of photolog or videos can help provide safety researchers with information about roadside obstacles, guardrail, culverts, and side slope, which could be fixed during other reconstruction. By having these data immediately available during the design phase, correction of otherwise potentially dangerous situations can be included. Such information is routinely referenced by designers and included in CAD files describing design plans. All that is needed is a means to capture these data and combine them with an inventoried database of such information that would be usable to researchers.

Many of these systems exist in isolation of a larger use. Because of decentralization, methods of keeping the data and then making them available vary substantially from agency to agency. Moreover, some institutional problems exist, especially where the data indicate some form of defect and "might" be subpoenaed as part of liability action. One state police organization has gone as far as telling the officers not to record roadway defects when they report a crash.

To summarize, the current problems in safety information are lack of sufficient data, inadequate data quality, and a lack of reliable historical data. These problems stem from limitations in current data gathering technologies, the associated high costs of obtaining such data, and a lack of focus or priority among most agencies in supporting the needs associated with understanding highway safety.

Strategies for Improving Safety Data

Although significant issues must be addressed to produce high-quality, usable safety information, opportunities exist to deal with these issues. Current technological advances and new approaches can be used to forward the cause of highway safety.

Technological Strategies

Some issues can be resolved through recent technological advances. However, for these technologies to be feasible, or effective, certain organizational and institutional actions must be taken. Indeed, some issues cannot be resolved by technology, but are basically related to the "human" aspects of the systems being addressed. Therefore, the consideration of strategies for resolving the issues listed in Appendix E includes both technological and organizational approaches.

The research team identified potentially applicable technologies (Figure 4). A technical memorandum was produced in which the applicability of these technologies was assessed.

Data Collection	**Databases**
Portable Computers	Relational
Pre-Recorded Data Readers	Object-Oriented
Artificial Intelligence	
Location Technologies	**User Interfaces**
Laser-Based Measurement	
Digital Photography	GUI
Aerial Imaging	GIS
	CADD
Data Communications	
	Decision Support
Cellular Systems	
RF systems	GUI
Hardwired (fiber optic)	Context-Sensitive Help
	Voice Recognition
Data Management	Artificial Intelligence
Optical Scanners	**Analytical Tools**
Artificial Intelligence	
Error-Trapping and Correction Software	Modeling
	Simulation

Figure 4. Technologies applicable for improving the quality of safety data to support highway design.

The results are summarized in Appendix F. Those technologies that can help resolve an identified issue are indicated by an "x" in the appropriate cell of the table in Appendix F.

Some general conclusions from this exercise were as follows:

- Technologies address most, but not all, issues. A single technology can help resolve more than one issue.
- Means are needed to ensure that complete traffic data are provided.
- Using a police patrol officer as a data collector at a crash scene is not desirable. Technology can be applied to mitigate the situation, but cannot completely resolve it.
- Desirable elements that can help resolve many of the issues associated with field data collection include the following:
  - A computer-based instrument for directing data collection, as well as recording the data;
  - Automated assistance in establishing location;
  - Automated methods for taking measurements, especially those that minimize judgments required by the data collector or eliminate the need for a collector to be in the field (e.g., remote imaging); and
  - Communication systems that allow two-way communication between field data collection instruments and data stores.
- Desirable elements to resolve many of the issues associated with data management include the following:
  - Automated data reduction and entry;
  - Extensive automated error-trapping and correction systems, preferably on-board field devices, and operating in real time;
  - Use of modern database management systems;
  - Use of a full range of graphical user interfaces, which allow integrated management of a wide range of data; and
  - Automated assistance for the management of the data.
- Desirable elements to resolve many of the issues associated with providing decision support capabilities include the following:
  - Comprehensive use of graphical user interfaces, including CADD, GIS, and virtual reality;
  - An accident investigation core to act as the "central processor" of the system; and
  - An extensive analytical capability, with emphasis on models that predict the effect of a design decision on safety.

Organizational and Institutional Strategies

A system operates in an organizational and institutional environment that can significantly influence the effectiveness of system operation. Several key organizational and institutional issues were identified and are among those listed in Appendix E. These issues are also listed in Figure 5. After some background discussion, this section of the report proposes strategies for resolving the identified issues.

Data as a Strategic Resource

Several of the issues identified suggest the need for some basic changes in the way highway-safety data collection, management, and delivery are thought of and handled. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) helped establish the importance of system management as a fundamental activity for state and local transport agencies. Furthermore, it recognized that a critical element of management is the provision of quality data on which to base information for decision making.

Only recently have the more advanced state governments begun to realize that they need to think of themselves as "enterprises." They are realizing that, as enterprises, they need to identify strategic resources for the operation of these enterprises and act to ensure that those resources are available to the organization. Some states have begun to identify strategic enterprise data as a key resource that must be maintained at the desired quality in order to support decisionmakers as they operate the enterprise.

The significance of this kind of approach is the change in "mind set" associated with the collection, management, and delivery of those data in the form of useful information. This contrasts with the traditional view, in which individual agencies within the governmental structure (usually the ones most dependent on the information derived from it) had an independent responsibility for the collection and/or maintenance of these data. These agencies often had to maintain these data sets in the face of budget restrictions that did not reflect the importance of these data as an overall enterprise resource. The result was often a deterioration in the quality of the data. Where duplication of collection was infeasible, for economic or other reasons, multiple users often depended on one agency to provide the data. That agency, however, may have maintained the data in a format, and with a quality, that was sufficient only for its use, without any consideration of the needs of other users.

The concept of strategic enterprise data results in a new view of their collection, management, and delivery. Safety data, of the type needed to deliver information to support highway design, should be recognized as a part of the strategic enterprise dataset. If this is done, the following will occur:

1. Safety data will receive support from the highest levels of state government, including accountability, at a high level, for agencies responsible for data collection, management, and delivery.
2. Safety data will be recognized as requiring a cooperative effort from all potential collectors, managers, and users.

Collection and Management of Roadway Data

1. Inaccuracies due to failure to provide notification of, and information about, changes made to the facility
2. Lack of integration of data files
3. Limited feedback regarding accuracy of data supplied

Collection and Management of Traffic and Control Data

1. Lack of history

Collection of Data for Traffic Crash History

1. Potential conflict among officer roles at the scene of a crash
2. Perceived need to establish fault
3. Lack of incentive to maintain quality
4. Inadequate training of officers
5. Sources of data may not be readily accessible to a crash investigator
6. Lack of linkages with other data bases result in officers collecting data that are already available, and usually in a more accurate and precise form
7. Poorly defined and inappropriate data elements and codes
8. Size and complexity of crash reports
9. Disturbance or destruction of evidence at the scene by emergency personnel and equipment
10. Lack of codes or elements for specific needs

Management of Data for Traffic Crash History

1. Duplicated local entry of data
2. The number of steps required for handling reports increases delay and likelihood of errors
3. Separation of duties among state agencies for recording data allows differing levels of quality and timeliness at the state level
4. Multiple databases, particularly local and central, increase delays in data available centrally and increase handling of data
5. State-level processing not integrated with local level, reducing feedback needed for improving quality and quality assurance
6. Change in forms without adequate review of entire process results in loss of data or quality of data
7. Review and quality control varies dependent upon attention and priority given to crash reporting by agencies
8. Lack of direct access by users reduces feedback needed to address quality, as well as usefulness of data being recorded

Use of Highway Safety Data

1. Limited computer literacy of designers
2. Lack of system coordination and integration is a major barrier to use, as it prevents real-time (or possibly any) linkages between roadway, crash and other databases
3. Designers will use significant resources to review crash reports for a site being studied (especially the narrative and diagram)
4. Most designers are not well trained in analytical methods involving advanced statistics and evaluation methodology
5. Most designers do not have an adequate understanding of the dynamics of operation of a highway to allow them to have a solid judgment on the operational and safety impacts of their design
6. Lack of consistent approaches to project assessment and decision making

Use of Non-Traditional Data Sources

1. No clear definition of the nature of the source along with the elements of data to be maintained
2. No standardized methods of identifying locations
3. Storage of data in widely dispersed locations under various storage methods, from notes to computerized databases
4. Lack of consistent description of the data gathered, i.e., one person will note that a sign is missing, the other will describe the sign and its location
5. Significant concern with liability issues when defects are codified
6. No responsibility provided to collect, maintain, and make data available

Figure 5. Organizational and institutionally related issues.

3. Funding of collection, management, and delivery activities will be included as part of a larger effort for supplying strategic enterprise data, making safety data less piecemeal and resulting in more efficient use of resources to produce the desired information.
4. Safety data can result in an organizational focus on effective delivery of quality information and support of decision making that does not currently exist.
5. Safety data can create forces for reorganization of the enterprise to facilitate the delivery of quality information and the support of decisionmakers.

The particular role of state and local design agencies in this effort will be primarily that of team members working with others involved in creating and using these enterprise information resources. Therefore, the design agencies will tend to be working in cooperative modes with other agencies. They will be dealing with policies and procedures established in cooperation with the broader set of data collectors and managers as well as information users.

A recent model for this trend toward cooperative collection, management, and use of strategic data is the implementation of GIS in government. GIS involves spatial data, and the information it produces is useful to a wide variety of users in government. The nature of the data, given current technologies, makes it expensive to gather or convert from other, non-automated, formats. Early attempts at implementation quickly resulted in the recognition that independent efforts

were not feasible and that the development of a useful GIS would require sharing of costs and other resources among the wide variety of potential users of such a system. This reality resulted in new forms of cooperation among agencies and, in some cases, reorganization of agencies to facilitate the process. As a result of the new interaction, new organizational relationships were established and greater sharing of data occurred than was previously realized to be possible. This created a synergy from which many benefitted.

The adoption of the strategic enterprise data concept is intended to have similar effects, but on a broader scale. GIS is understood to be just one aspect of this critical data set. Highway safety data are another aspect. As aspects of collection and management of safety data are dealt with, it will be necessary and desirable to do this as part of a team consisting of the broader set of members of the system who collect, manage, and use the data. These will include representatives from areas well removed from highway design activities, but who are members of the highway safety system. Decisions on policies, procedures, and systems will need to be made jointly to ensure that the various user needs will be met.

Meeting Varying Needs of Users of Safety Data

Variation in user needs for safety data is shown in Figure 6. Safety data can be characterized as follows:

1. Crash: generally including information on the PCR, but also including supplementary crash investigation data that may be collected;
2. Traditional Highway: including roadway inventory, photolog, and traffic counts; and
3. Nontraditional Safety: including highway maintenance, citizen complaint, and pavement management data.

Although this is a relatively simplified view of the set of safety data, it demonstrates the point, as shown in the four subdiagrams of Figure 6, that each type of user needs different parts of these datasets. Law enforcement users, for example, may have more need for crash details dealing with specific identifiers of individuals and vehicles. Planning-level users may need a small part of each of the datasets, while developers of design guides may need a fairly in-depth set of

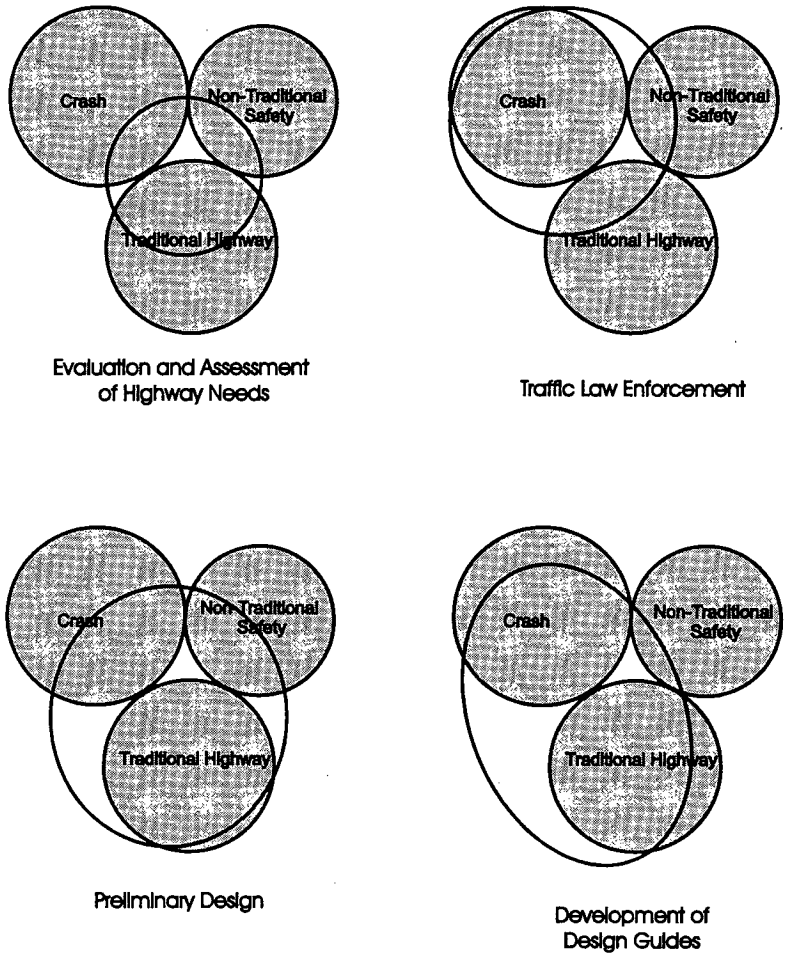

Figure 6. User needs for safety data.

crash and highway data. Although data needs may vary, there is still an overlap in the need for specific types of data. The location of a crash is one example of a data element commonly needed. For that example, however, different users may have different needs for precision. For example, the law enforcement user may not need as great precision for the location of a crash as the designer desires.

Meeting Specific Needs of the Design Users of Safety Data

When focusing on delivering information for design decision support, the potential users are primarily the design community. The information needs of designers, and their degree of control, should, therefore, be of first consideration in the development of DDSS. However, even within the design process, there will be a need to reflect varying data and information needs (as Figure 3 demonstrates) because decision making can differ substantially at various stages of the design process.

Proposed Strategies

Organizational and institutional strategies have been identified to help resolve the issues listed in Figure 5. These issues, categorized with respect to basic areas of action, are as follows:

1. Policy Actions: These address issues outside the immediate context of design agencies. They deal with policy at the highest levels of national and state government. As such, the design community can be most effective as an active member of a broad-based group advocating these changes.
   a. Establish the importance of safety data in the overall state operation, giving it the status of strategic enterprise data.
   b. Establish requirements for specific types of safety analyses to be performed and a consistent set of safety performance measures to be used at specific stages in the highway design process, as appropriate for each stage of the process and regardless of the source of funding for the project.
   c. Establish requirements and accountability for appropriate state agencies, as well as local agencies receiving funds from the state, to be involved in a safety data collection and management oversight function.
   d. Establish policies and procedures allowing access to high-precision satellite images for use in measuring physical features of the highway, traffic, and environment.
2. Organizational Actions: Organizational actions may be taken without high-level policy or legislative action to organize more effectively to achieve the desired effect on data quality and usefulness. Many of these actions are also to be accomplished at a level of government above those in which design activities usually take place.
   a. Reorganize, as appropriate, state agencies involved in highway transportation to facilitate the efficient and effective collection, management, and use of safety data as a strategic enterprise data resource.
   b. Establish organizational entities, as appropriate, to provide specialized services for data collection and management of safety data, with appropriate incentives for quality performance.
   c. Establish organizational entities dedicated to quality assurance of safety data.
   d. Coalesce state and local agencies into a cooperative safety data collection and management function.
3. Legislative Actions: In some critical areas, legislative force is required to ensure that agencies are accountable and to deal with social aspects of data collection and use.
   a. Establish and authorize a data collection and management function to oversee the provision of enterprise strategic data to users at the state and local level.
   b. Allow and protect the real-time on-board recording and use of vehicle-dynamics data.
4. Funding Actions: Funding mechanisms and programs need to be addressed. A difficulty with the specific strategy is that the direction of government is toward reduced rather than greater funding. However, strategies are noted in order to provide the basis for allocating funds to help accomplish the overall strategies. In some cases, funds can come from reorganization of priorities. In others, creative funding mechanisms are possible, including public-private partnerships.
   a. Fund an authorized data collection and management function to allow it to support collection of data through agencies or privatization.
   b. Fund major technological advancements to systems for the collection, management, and use of safety data.
   c. Fund a comprehensive research program.
   d. Fund a comprehensive training program.
   e. Establish mechanisms for cooperative funding of strategic enterprise safety data by all users, ultimately seeking self-sustaining operations.
   f. Establish performance-based funding for highway projects, including safety performance measures.
5. Training Actions: The capability of design decisionmakers will continue to be key to the effectiveness of any design process. Technological advances will increasingly be able to capture expertise and maximize the effectiveness of an individual. However, for the foreseeable future, individual decisionmakers will still need to better understand the highway system and its operation, as well as how to apply analytical tools at their disposal to produce better quality designs.

a. Offer training for designers in principles of highway safety applicable to highway design.
b. Offer training for designers on principles, practices, and tools of safety analyses.
c. Offer training for users on new systems instituted for making improved safety data available to support highway design.

6. Research Activities: Several research efforts underway can help achieve system objectives. The development of the IHSDM is a major example.

a. Develop improved design guides and standards based on improved safety data.
b. Develop crash-impact models and factors for use when assessing alternative design actions.
c. Develop tools to apply design principles and relationships consistently for all types of design projects.
d. Develop new tools and methods for presenting and visualizing highway safety data.

CHAPTER 3

INTERPRETATION, APPRAISAL, AND APPLICATIONS

SYSTEMS CONCEPT TO PROVIDE IMPROVED INFORMATION

The data needs, related issues, and potential strategies that constitute the findings of this project have led to the recognition of a need for a comprehensive system to provide designers with safety data to use in making design decisions. This chapter defines the concepts for a system to collect and manage highway safety data and deliver improved safety information to assist with design decisions. It describes a framework for the system and how the system can be developed over the short, medium and long term. The last section of this chapter assesses the proposed system in terms of its potential benefits to the design community, as well as to other potential users of safety data.

System Goals and Objectives

A set of system goals and objectives has evolved during the project. Figure 7 lists the goals (which also appear, along with the related objectives, in Appendix G).

System Framework

The recommended framework for a DDSS is shown in Figure 8, which includes the following:

- User interface,
- Decision support module,
- Information presentation module, and
- Design analysis module.

The system provides user interface, which should be as intuitive as possible for both its end-users and managers. Ultimately, the use of voice, and even eye movement, will be a means of communicating with the system. In the foreseeable future, several forms of graphical interface will be applied. A combination of a standard graphical user interface (GUI) and the CADD/GIS would be appropriate for the design context. The two should be fully integrated, so the user can move between them seamlessly.

Data collection and data management activities, as well as the resulting set of data stores, are shown in the top-left portion of Figure 8. They are essential to the success of efforts to improve the consideration of highway safety in the design process. (These are shown with little detail here—much has already been presented about these modules.)

The end-user (designer) primarily interacts with the system through the decision support module. This module provides an "intelligent" core to the system and is probably the most technologically advanced concept being applied. In its ultimate form, it will act like a central processing unit that manages the operation of a computer. All inquiries will be input and results output through the decision support module. It will be programmed to interact with the user by asking questions and making suggestions on how to proceed at each stage:

1. Inquiry (as the user makes an inquiry, the decision support module will ask the user appropriate questions to help focus the inquiry and make it as clear as possible);
2. Analysis (offers suggestions and arrives, interactively with the user, at the appropriate approach to the analysis, making sure that methodological issues are addressed);
3. Interpretation or problem identification (assists the user in interpreting results of the analysis, highlighting patterns or unique findings, and raising questions that could lead to additional analyses);
4. Countermeasure identification (using expert systems and results from analyses, provides suggested actions for improvement);
5. A priori evaluation (assesses alternatives using crash-reduction factors or other safety impact model output, as well as the results from a whole array of design analysis tools of the type envisioned for IHSDM); and
6. Presentation of the results (interactively works with the user to select the best graphic format for presentation of results, as well as production of written reports).

Ultimate development of this module will require extensive application of advances in artificial intelligence, including expert systems. In the interim, pre-established relationships, principals, and expert opinions can be used in a less interactive manner than is ultimately envisioned. This will suffice to introduce the concept of a decision support module without requiring an extensive research and development effort. For example, it is feasible to provide the user with a set of relationships among crash patterns, possible

A. The system will deliver information to the user which is useful for the particular stage and activity of the design process.

B. The system will facilitate the integration of multiple data sources into the design process.

C. The system will facilitate direct use by decision makers.

D. A system will be established and maintained to collect and manage safety data to support design decisions.

E. The system will be feasible to implement.

F. The system will meet requirements and constraints of the organizational context in which it is designed to operate.

Figure 7. Goals for a design decision-support system for safety.

contributing circumstances, and candidate countermeasures in a semi-intelligent context.

The information presentation module contains the basic software needed to display information derived either directly from the data stores or generated from the design analysis module. The CADD/GIS environment allows for several information outputs to assist designers in evaluating safety. These include the ability to generate two-dimensional views (e.g., ground-level or aerial), three-dimensional views, dynamic simulations (e.g., drive-through views), and visualization of driver-eye sight lines. These features are all available or under development in commercial highway design CADD software. In addition to CADD and GIS systems for displaying primarily spatial data, use will be made of the following:

1. Standard presentation software to produce digital images (scanned or photographed);
2. Standard business graphics to produce familiar graphs;
3. Standard scientific graphics designed to produce unique views of data that help the user interpret the information (these graphics are of the type being developed through the current science of data visualization);
4. Standard spreadsheets and report generators to tabulate information;
5. A series of special devices proposed by the team to aid designers in summarizing and interpreting data about a site, including:
   a. Site Time Lines: This graphical device is often employed in disciplines such as history, archaeology, and paleontology. A time line will be available to the designer for any aspect of the history of the site. It will be possible for the designer to display, for instance, a history of the use of traffic controls at the site. The time scale on the monitor indicates, through symbols placed at the appropriate places, changes that occurred in the traffic control or roadway characteristics at the site. The user will then be able to click on any of the symbols that appear along the time line to get a display of further information about the change. The changes could include such things as going from stop control to signalized control, a change in signal timing, or roadway modifications.

      The user may then, from the same time line, request comparisons of crash experience or other operational data before and after the change. Time lines will help the designer see what has been tried to improve operations and how well it has worked. This will give insight in selecting proposed new countermeasures.
   b. Display of Narratives and Diagrams: The individual narratives and diagrams from crash reports for the site under study would be aggregated, summarized, and presented in a standardized format in order to ease review of this information. Many designers, doing project-level analyses, want access to the narratives and diagrams on the original crash report. This can be time consuming to acquire, review, and summarize. However, designers find this to be cost-effective because they have consistently found crash reports to be miscoded, rendering standard tabulations of crash data to be of limited use.

      The best way to standardize narratives and diagrams and to automate them will be determined as part of the research and development effort for the proposed system. However, immediate access to scanned images of the crash report or that portion of the report containing the narrative and diagram is feasible. Thus, a near-term implementation of this type of tool might involve linkage to the images of narratives and diagrams through a hyperlink established on a site-crash profile tabulation or collision diagram. An analyst reviewing the site profile or collision diagram could click on the appropriate symbol for each crash to immediately retrieve and review the narrative and diagram for that crash.

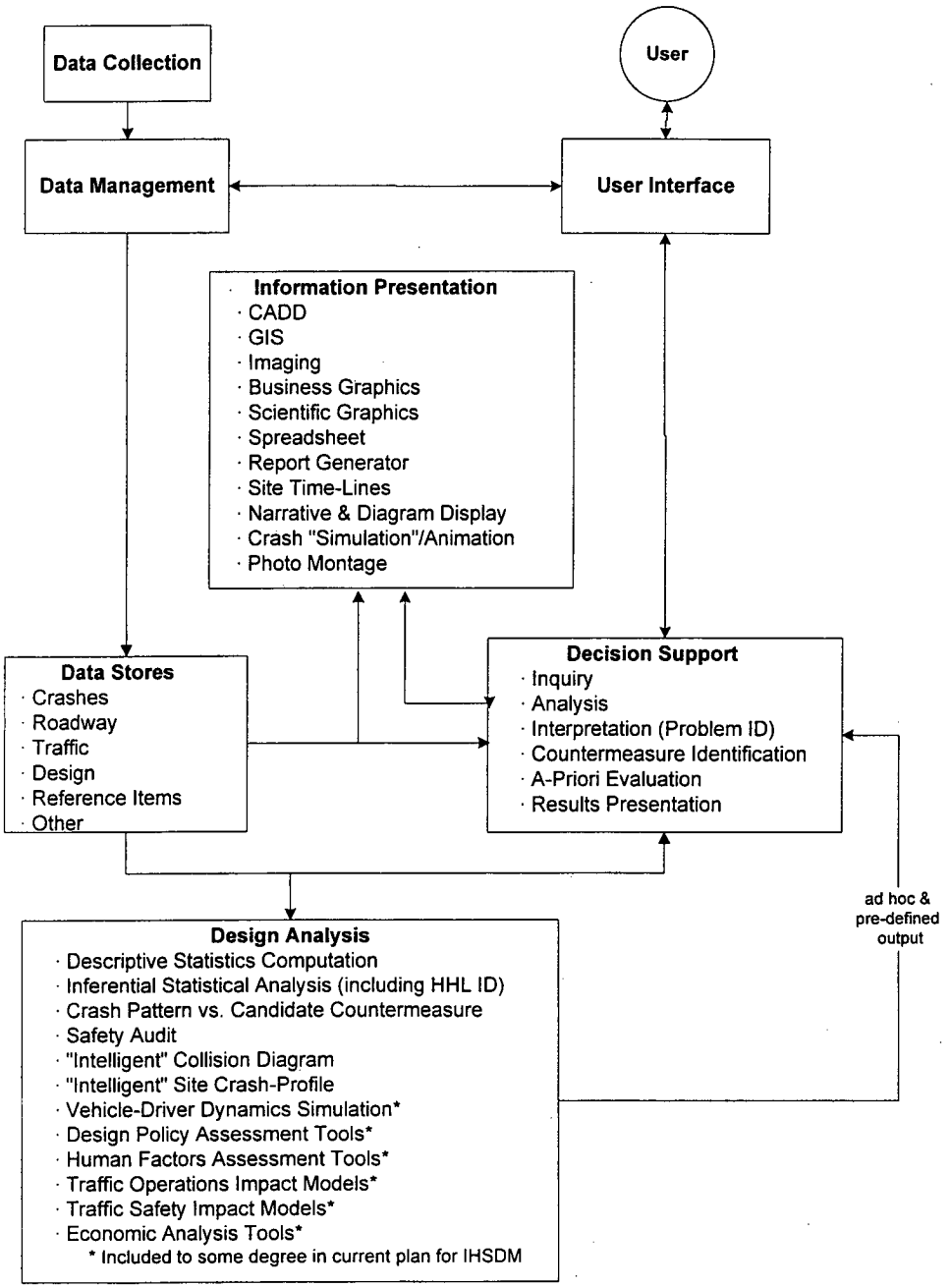

Figure 8. Generalized concept for a design decision-support system.

c. Crash "Simulation"/Animation: This is an extension of the previous method for displaying crash information. It is possible to display an actual simulation, or at least animation, of each individual crash, on the basis of data provided in the crash report and supplementary crash investigation reports prepared for serious injury crashes. Software exists for simulating a crash, but the data requirements may not justify its use in this context. However, simplified simulation or animation capability is feasible. Designers may find this useful, especially if the animation is displayed on a photomontage overlay of the site or at least a CADD representation of the site. Seeing the dynamics of crashes may provide the designer with useful insight on contributing circumstances and patterns not otherwise detectable. As in the previous item, the designer could access the animation by clicking on a symbol associated with an individual crash, as it appears in a site profile or collision diagram.

6. Use of digital aerial photos to create photomontages with CADD data and display of collision diagrams. This will help with the interpretation of the information by relating the crash more directly with the physical context.

The design analysis module will provide tools for analyzing existing and proposed designs. It will draw on the best analytical devices available at any given time. Traditional statistical analyses are included. This will involve the development of descriptive statistics, usually in conjunction with a site crash profile. It will also include use of inferential statistics for identifying high-hazard locations and other methods for determining over-representation of patterns or attributes of crashes and their variability over space and time. Included will be the development of an "intelligent" collision diagram. This device will display crashes using similar graphic techniques as are currently used for collision diagrams, but will be able to identify and highlight over-represented patterns. In addition, each crash on the diagram would be created as an "object," allowing the user to select it and obtain further details (e.g., the narrative and diagram for the crash, as described above) immediately. Similar kinds of capabilities can be built into traditional tabulations (e.g., a site crash profile).

The types of analytical tools discussed to this point are designed to facilitate identification of the underlying contributing factors. They are intended to allow the designer to investigate the data to the level of detail desired, by performing a series of inquiries, each of which can "drill down" further into the details available in the data set.

Figure 9 shows how this will work. Using GIS and CADD, the site under study is displayed. The user can then request general summaries of crash experience at the site. On the basis of these data, the designer can request further details in the form of collision diagrams, bi-variate graphs, and over-represented patterns in the crashes. As desired, the designer may then look at individual crashes, review the narratives and diagrams, and view an animation or simulation of selected crashes. Each of these steps explores the multidimensional crash data available in the system further.

In addition to these traditional analytical tools, the module will also provide the designer with an analysis using safety audit procedures. Safety audits will be used to summarize and assess the results from other design analysis tools available in this set.

Another element of the design analysis module will provide designers with a tool to identify likely contributing circumstances and candidate countermeasures for consideration. It will use the pattern analyses performed by using other analytical procedures available in the module. In its most basic implementation, the designer will have a set of tabulations that reflect expert opinion and based on operational experience and research. In the ultimate form, the tool will use artificial intelligence capabilities, including expert systems, to provide a highly interactive aid to the designer.

In addition to these tools, there will be a series of analytical devices to test and assess a proposed design. These tools are among those proposed for the IHSDM.

1. A simulation of vehicle-driver dynamics will be useful to test the physical adequacy of the design. To the extent that the model can reflect the information processing capabilities of the driver, as well as driver control motor-skills, it will be useful to test areas such as information overload and design consistency.
2. Until human factors features are adequately represented in simulation, design analysis tools can be employed to analyze these. Positive guidance, information loading, and other principles of human factors in driving can be built into an analysis routine.
3. A design policy review element can be used to identify where design policy has been violated. It also can assist in the analysis for a possible design exception.
4. Models for predicting the operational and safety effects of a given design would be part of an ultimate implementation of the module. However, safety-impact modeling will have to progress substantially before this aspect can be implemented.
5. Economic analysis tools also will be provided to translate the proposed design into terms allowing a cost-effectiveness analysis to be performed. Therefore, means will be included for estimating project capital, maintenance, and operating costs, as well as for determining user costs.

System Development

The development of the proposed system will evolve as funding is available, organizational and institutional requirements can be met, and technologies become viable. A view of system development, shown in Appendix J, provides for the short (1997–2005), medium (2005–2010), and long term (beyond 2010). The time frames are somewhat arbitrary because the responsiveness of government is impossible to project and the progress of technology is difficult to predict (but is usually ahead of expectations where commercially viable applications are involved). Even given these limitations, the progression of system development outlined in Appendix J is considered feasible. The five major modules of the system are characterized as follows:

1. Data collection,
2. Data management,
3. User interface,
4. Design analysis, and
5. Decision support.

Appendix J provides a tabulation of the technological strategies previously introduced, placed within a time frame,

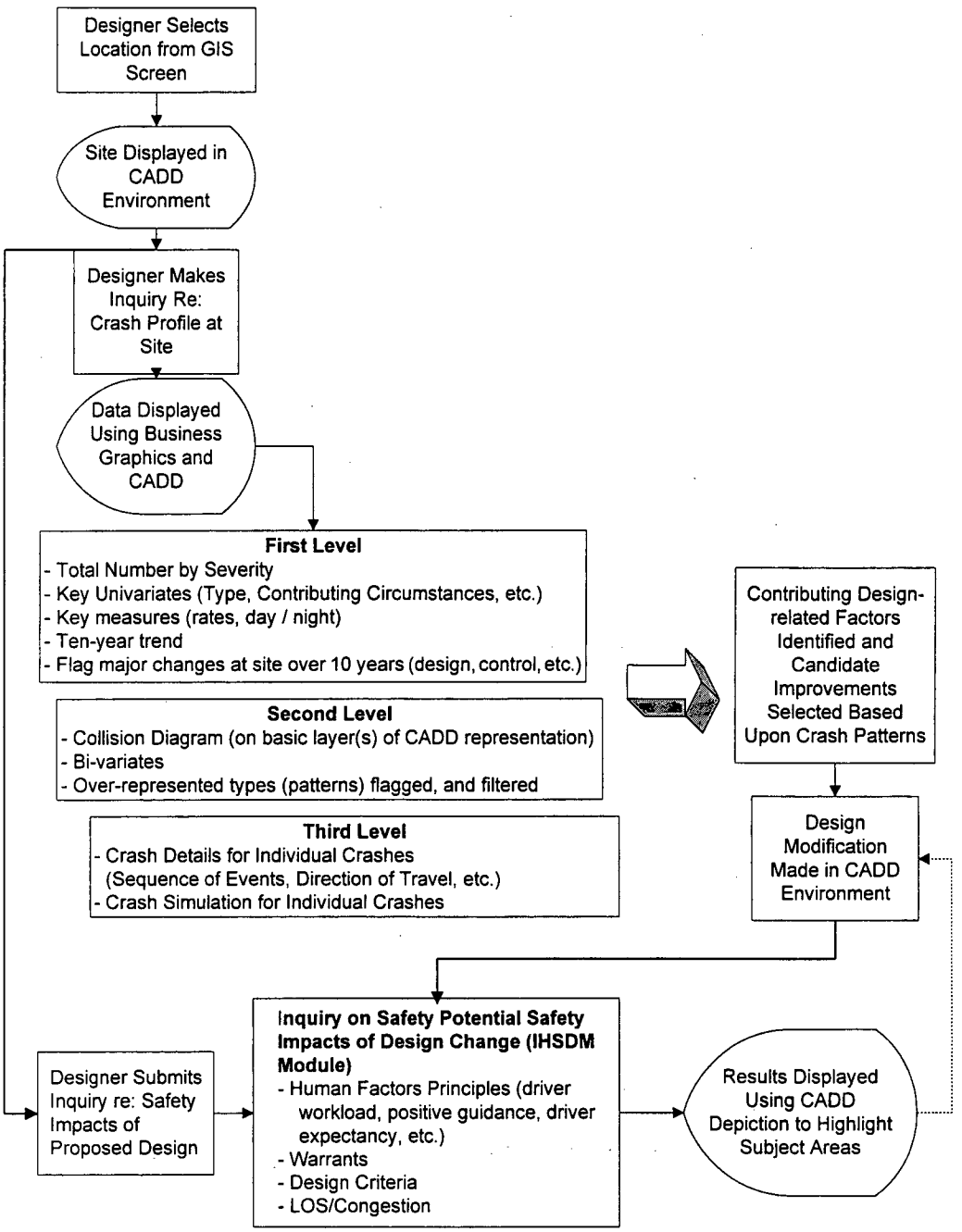

Figure 9. Example of system use by a designer (with "drill down" options).

and related to a specific system module. To these must be added the requisite organizational and institutional actions discussed in the section above on proposed strategies. Non-technological actions are needed to facilitate or make feasible the development of system technologies.

The "Current Conditions" column is included to provide a reference base. It is not possible to characterize an "existing condition" because the variation among agencies is so wide. However, the research team sought to describe what they saw as a "typical" condition in state government today.

Data Collection

Current systems are dominated by manual data collection methods for crash and roadway data, while traffic counting systems are somewhat more automated. The content of data being collected is not complete or consistent. There are many quality problems, with accuracy of location being a major one.

The short-term implementation of an improved data collection effort will involve the use of portable computing devices and some automated measurement systems, including

laser measurement and GPS. This could substantially improve the quality of the data being collected and make it feasible to increase the coverage of crashes and roadways.

"Data warehousing" is also introduced in the initial development period. This concept, arising from current commercial information systems, recognizes that many pieces of data are being captured temporarily by automated systems (e.g., sales information at cash registers and traffic counts from detectors in signal and other traffic control systems). If these are "warehoused," they could be useful for later analyses (e.g., market analysis). The advancements in data storage technology allow these data to be retained at relatively low cost, so that they can be accessed for detailed analyses. In the case of the DDSS, the warehousing of traffic count data from the multitude of detectors in place in a roadway system can add greatly to the ability to derive more accurate exposure information.

The longer term view of data collection is to maximize automation of the process, eliminating the use of paper and minimizing the use of people. In the mid term, this may be accomplished by full integration of automated measurement devices with a portable computing device, use of imaging systems for obtaining physical data, and the gathering of data directly from vehicles involved in crashes, using on-board recorders of vehicle dynamics. In the long term, remote sensing and imaging technologies will make it feasible to eliminate the use of field personnel for collecting physical and traffic data and even eliminate the need for the collection of some crash data.

Data Management

Safety data are managed in a series of independent data sets by a myriad of agencies who generally are not coordinating their efforts. As a result, there is little file linkage, much inefficiency, and a general lack of quality assurance. Although there are significant exceptions to this, what is described here represents the "average" condition.

The initial stage of development of an improved system focuses on enhancing the quality of what is collected, achieving coordination and linkage of related systems, integrating nontraditional sources of safety data, providing document support, and applying the concept of data warehousing. This will require the development of a data communications infrastructure.

Longer term development will focus on extensive system integration of strategic enterprise data and will seek to eliminate control by individual agencies. Ultimately, technologies will be used that will allow distributed databases to exist at the locations most appropriate for the specific types of data, but, from a data management perspective, forming a virtual, unified data store. This will enable multiple users to access the data readily for a multitude of purposes, thereby creating a "data mart."

User Interface

Currently, systems for safety analyses and design development are independent and have different user interfaces and operation. Safety data systems use either terminals with menus or, in some cases, a GUI. GIS increasingly is being used to access roadway and crash data, as well as to display some of the results of the inquiries. CADD systems are increasingly used for design development. These have their own type of specialized GUI.

The near- and mid-term emphasis will be on the integration of GUI, CADD, and GIS into a single interface that is intuitive for the user. This supports some of the goals to achieve complete system integration.

Over the long term, the research team anticipates that the user will be able to interact with the system, not only with a GUI, but also using natural voice/language and in the context of virtual-reality displays. Each of these advances has the objective of minimizing the barriers to accessing safety data and fully using the information that the system can produce.

Current systems generally are limited to providing users with hard-copy outputs of tabulations. Some basic graphics are in use, including straight-line diagrams, standard business graphics, collision diagrams, and increasingly, use of GIS in which every object, line, or polygon is located precisely in x-y coordinates and in which various objects can be displayed in layers allowing manipulation of each layer. Integration of the data systems and the production of graphics is minimal or nonexistent, requiring users to do considerable manual reentry of data from outputs before producing the desired graphics.

Some improvements for presenting results are feasible in the near term. Most are oriented to increased use of graphics to present information. Just the increased use of standard business graphics can greatly enhance the user's ability to interpret results. Graphic representations should be provided that allow the user, by using a GUI, to click on an "object" within a graphic to get additional detail and numerical values via hyperlinks. Where tabular data are presented, great care must be taken to design it for easy interpretation, letting user needs rather than computer or printer capabilities control. The system will also be able to produce graphics specially oriented to design use, including intelligent collision diagrams and time lines for the features of the site or some of its operational measures. Each of these would also be designed with hyperlinks to further detail to facilitate "drill-down" analysis. These tools were discussed above in the section describing system components. Three-dimensional representation of existing and proposed designs will be possible at this stage of development, using the capabilities of CADD systems.

For the mid term and longer, the emphasis will be on the adoption of new approaches to data visualization and the application and integration of animation and simulation. Virtual reality will be used to "experience" alternative designs and, possibly, to "experience" a crash.

Design Analysis

Current design analyses involve minimal use of inferential statistics applied to safety data. High-hazard location

identification is the primary area in which statistical methods are employed today. In general, the development of crash reduction factors and attempts to develop safety-impact models have not adequately considered the requirements of experimental or quasi-experimental design. Thus, valid results have not yet been produced. Although various design analysis tools have been proposed, few of them are in use as a standard part of the design process.

In the near term, the system will incorporate a standard set of valid statistical techniques for doing various analyses. Criteria will be established for their use, and they will be built into the decision support function. Similarly, valid experimental and quasi-experimental techniques also will be established for use in the system. A support function within a state's design group is needed to work with designers to ensure that valid analyses are conducted. A safety audit procedure will be incorporated to better structure the review of the safety of a given design.

In the mid to long term, as data quality and analysis routines are improved, a set of valid procedures can be developed for assessing the relative safety improvement resulting from alternative designs. The earliest implementation of this is likely to be a set of crash-reduction factors. Also, as IHSDM is implemented, the system can integrate those various components. Improved data quality and analysis capabilities will also make it possible to improve design guides and standards, thus enhancing the systems capability to review and assess alternative designs from the point of view of design policy. Anticipated in the long term is that simulation of operations will become a major means by which the relative safety of alternative designs may be assessed.

Decision Support

Decision support is virtually nonexistent in highway safety analyses. At best, design guides and standards and some related references may be considered decision support tools. In actual practice, decision support resides in the experiences of senior design engineers (the true experts), who provide advice and counsel as requested.

The technologies associated with decision support are in the early stages of advancement. Therefore, initial development of a decision-support capability will be less interactive and automated than in later stages. For the next 5 to 10 years, it will be necessary to depend on the use of specially trained individuals as decision support specialists who can be available to designers. One state has created what it calls its "decision support" center, which acts as a service bureau for safety data users. In addition, however, certain knowledge can be archived and integrated into design systems to allow the user ready access. For instance, tables are available that relate crash patterns to possible underlying contributing factors and candidate strategies for eliminating the problems. These can be built into a system to allow the user ready access (i.e., an on-line reference book). Similarly, published guidelines exist for selecting the appropriate inferential statistical method for a given analysis. This type of guide also can be automated and made readily available to the designer who wishes to perform ad hoc analyses.

In another 10 years and beyond, the science of AI should have progressed to where a system can be developed to directly assist the user, in an automated manner and at various stages of the design process using expert systems and other techniques. The system will serve a supporting function, not replace the decisionmaker.

Closure

The rate of the development of the proposed system will be constrained either by the pace of advancements of technology or the appropriate organizational and institutional actions as outlined in the section on strategies. More likely, especially in the near term, is that the latter will control, more than the former. A major example is that system integration technologies probably will not be feasible to implement until the concept of an enterprise, strategic data resource is fully institutionalized. The technologies essentially exist, but the organizational will to move forward in this manner may take some time to develop. The design community must recognize the importance of proceeding in this direction, play its part in moving government in the right direction, and do so at a pace appropriate to the importance of this information resource.

FUNDAMENTAL ARCHITECTURE FOR A SYSTEM TO IMPROVE THE SUPPORT OF HIGHWAY DESIGN

Examples of a Process

The DDSS is structured to assist the designer at the various stages of the process. It will be capable of generating information at various levels of detail from the most aggregate to the most disaggregate. This will allow the user to perform a series of inquiries in a given area, each of which would enable the user to "drill down" further into the details available in the data set. To demonstrate this concept further, several key activities performed in the design process are diagrammed and the processes are described, indicating how the DDSS would assist the designer. This demonstration of system operation provides further documentation of the fundamental architecture of the system being proposed.

The processes that have been detailed may be found in Appendix H. Five scenarios were selected:

- HHL identification,
- Problem identification for a project,
- Preliminary design project,
- Analysis of design exception, and
- Development or refinement of design standards and criteria.

Data Needs

The system defined and examples given require a fairly comprehensive set of data to generate the desired information. Figure 10 is a diagram of the safety data desired for the system. These data are divided into four main categories:

1. Crashes,
2. Maintenance,
3. Site Experience, and
4. Highway.

Each of these is further subdivided into classes of data. A relational database design requires that the data be linked where appropriate so relationships can be established. The database for the DDSS will primarily link the data through the associated location code. Location coding will be determined on the basis of geocoding, with equivalency tables to convert from other existing systems, until the entire system is on a geocode basis.

Time would be a secondary basis for linkage. Time is also included because crashes are events (i.e., time related), and the condition of the highway changes over time, so any particular attribute exists for a given period. This feature of the database is shown in the entity-relationship diagram in Figure 11.

Specific types of data desired within each class were defined in Appendix D, which serves as the initial definition of a data dictionary for the system. An extensive discussion of issues associated with the collection and use of safety data has been included in reports from other tasks and will not be repeated here.

Perhaps the greatest difficulty in obtaining needed data is the disbursement of responsibilities and even databases that contain the requisite data. This disbursement grew, in part, out of different sources from which data evolved with differing objectives, criticality of collection, and responsibilities of the agencies reporting them. Most notable are the differences between crash data and roadway data. For crash data, the primary collector has been the police who are responsible for enforcing the law. Their objective in obtaining data from crashes is to meet case obligations, both criminal and civil, that may arise from the crash. Most important, where the crash is minor and the outcome likely to be simply an insurance matter between the involved persons, the police may simply be acting as a source of verification rather than as a crash reporter.

Reflected most notably is the differentiation in degree of importance given location of the crash. For the police, unless a criminal case is forthcoming (e.g., reckless homicide), they are more concerned with ensuring that no confusion can arise

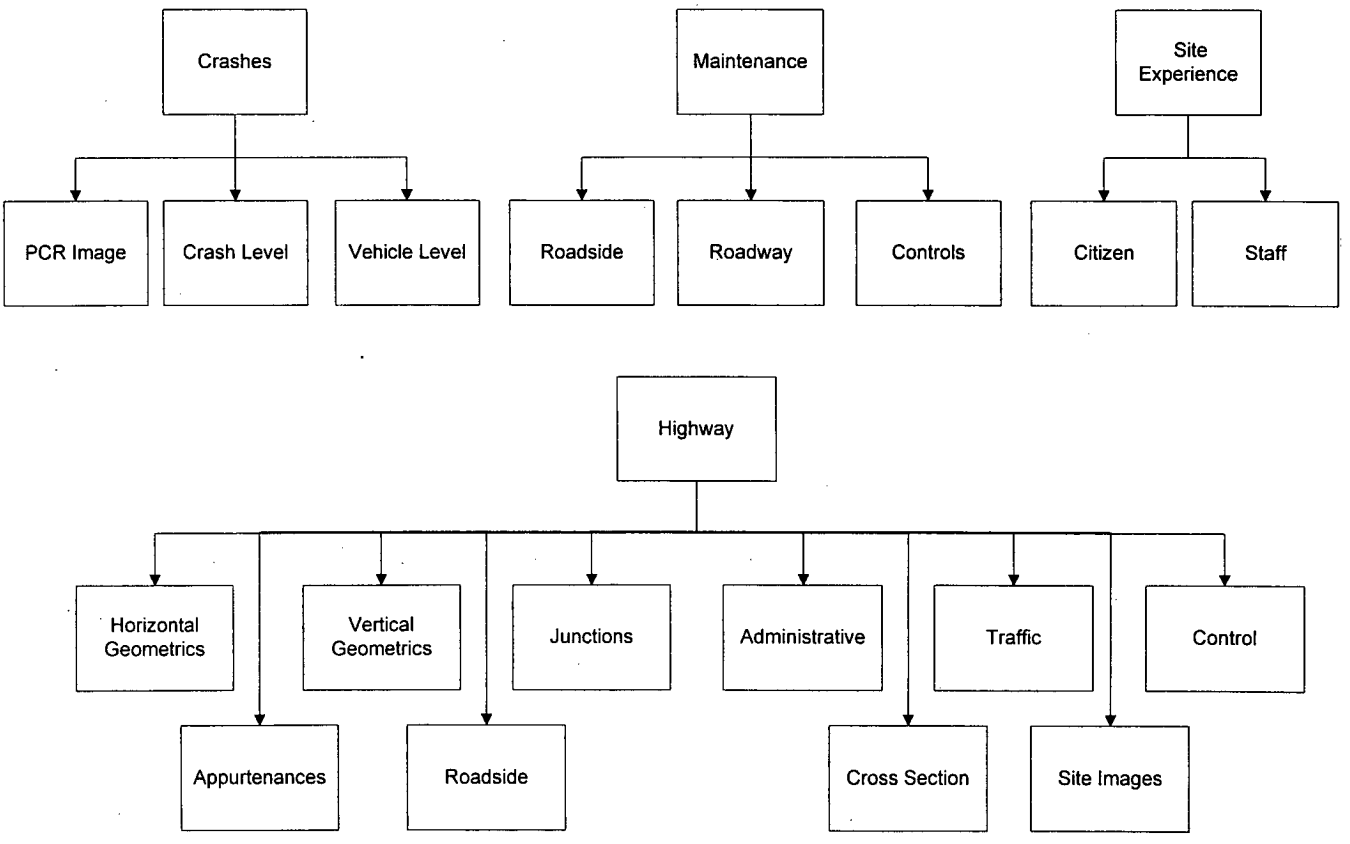

Figure 10. Safety-data structure diagram.

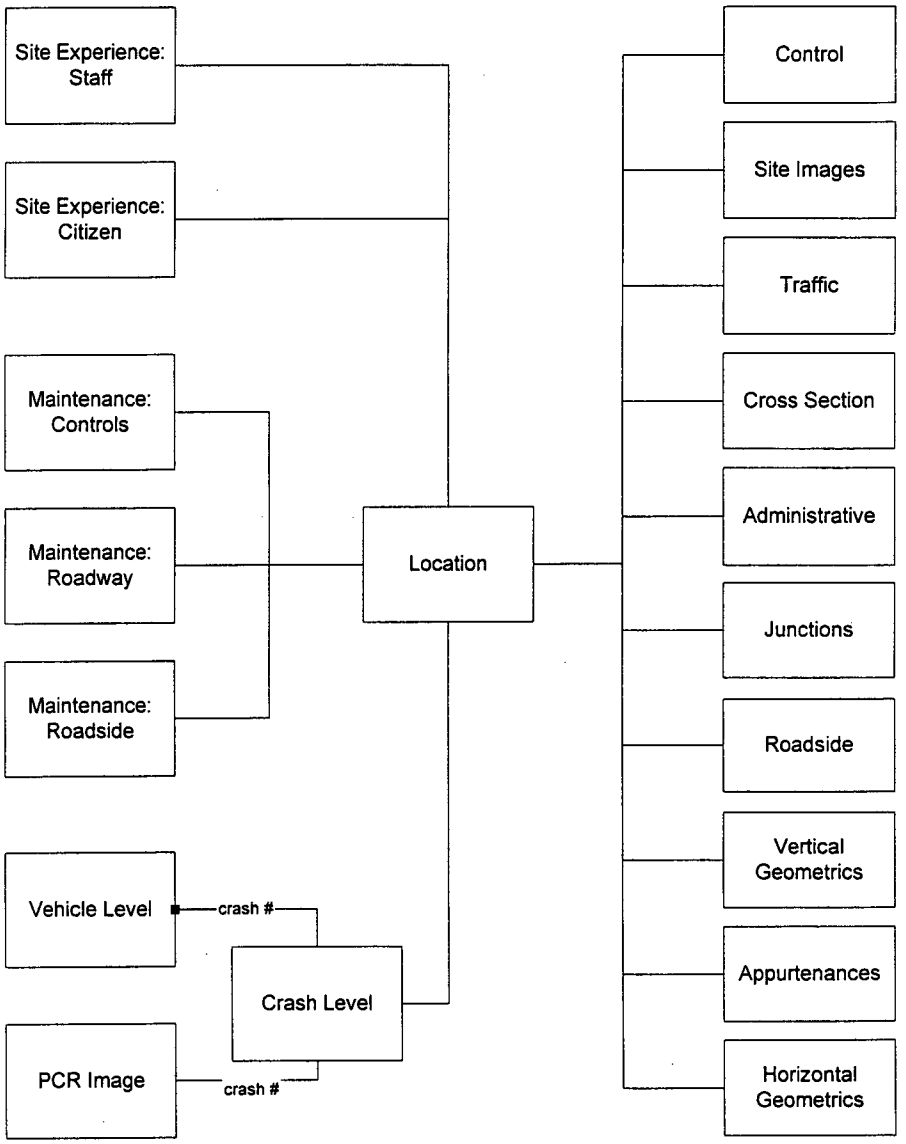

Figure 11. Safety-data entity-relationship diagram.

among cases representing different crashes at the same location. Because few locations have multiple crashes even in one day, the approximate location, date, and time are sufficient to identify the crash. On the other hand, precision in location can be critical to engineering needs. Even the difference of 100 meters can make the difference between highlighting a potential hazard (e.g., sight distance at a vertical curve) and a potential "chance" event. Moreover, for the police, each crash is an independent occurrence; for the engineer, the accumulation of crashes at a given site is of interest.

Conversely, the collector of roadway data—usually the highway agency—has a direct stake in those data collected. They will be of value in the design, construction, and maintenance of the roadway. The data also have become increasingly important in protection from tort actions. To ask the highway department to collect data regarding traffic or criminal violations on their roadway would result in such data receiving a relatively low priority given the limited direct value to that roadway agency.

Yet, the crash data are important in the safe design of roadways. In many cases, the roadway data may be important in relationship to law enforcement (e.g., poorly timed traffic signals that might encourage traffic violations). However, because the police have not been trained to use crash data in a larger context (e.g., traffic safety, which relates the motorist and roadway as a single entity), they will not have a stake in collecting data that can be used to help improve design.

Ultimately, the collection of valid data, especially about location and sequence of events, which is so important to safety in design, will have to depend on sources other than the police. One of the most promising is the use of "black boxes" on vehicles similar to those now used on airplanes which,

when coupled with GPS data, could provide many of the data now lacking on crash reports.

Simply having the data available at the same physical location does not necessarily mean that data are shared easily. Some states have enhanced their systems so that both the crash and roadway data are available to both sets of users interested in the information. However, linking systems is costly, especially if the databases reside on different platforms under different operating systems and database management systems. Obtaining the necessary funds in the current economic climate must clearly be accompanied by offsetting benefits to link the databases.

The one category of data that has been overlooked by most agencies has been that of site experience other than crashes. Generally, the most useful data probably are those which arise from the motoring public and highway maintenance personnel. The data take the form of complaints and comments. They can provide insight into situations that may be unsafe but that have not led to crashes. Using these data to supplement crash data may assist in correcting design problems before they become more costly in terms of crashes or even possibly as tort actions.

Just as important, a demonstrated response or sensitivity to citizen complaints is consistent with the approach of progressive transportation agencies. Design, operation, and maintenance of the highway system are increasingly being viewed as a service business with a customer base (the traveling public). Establishing a means of capturing and using complaints from this customer base is seen simply as a good business practice.

BENEFITS TO THE HIGHWAY-DESIGN COMMUNITY

Implementation of the proposed system should substantially benefit the highway design community as well as others. The research team has performed a qualitative assessment of these benefits. The assessment is based on the following activities:

- A review was performed of the typical highway project development process. State DOT staff were interviewed. The co-principal investigator drew on his working knowledge of design development and the current use of safety data.
- A panel of senior design staff from the Wisconsin DOT was assembled. They were interviewed about recently completed projects, safety issues, key design decisions, and their use of safety data during project execution.

The most effective way to describe system benefits is through examples. A set of "design scenarios" was prepared and analyzed. These hypothetical designs allowed for determination of benefits. The complete discussion of the designs appears in Appendix I. A summary of some key benefits appears as Figure 12.

Conclusions from the Discussions

Design Standards and Criteria

Any discussion of benefits of improved safety information must include reference to geometric design criteria and standards. A fundamental principal of design criteria is that they represent "safe" practice. The design process focuses on the use of design criteria. Designers implicitly believe that their designs are safe if they adhere to the design standards and criteria in place.

The state of knowledge regarding the relationship between accidents and safety was reviewed early in the research. A clear conclusion from the literature is that there is much less safety sensitivity in many geometric elements than has been assumed historically. Whether this is because of the lack of quality data to support standards analyses or because the design profession has overestimated the relative importance of safety is open to question. Regardless, without a system that provides the information, it is difficult to see how highway design standards can be viewed as optimized with respect to safety.

Benefits to society would accrue as more complete safety analyses and refinements to design standards based on safety are made possible. DOTs would be able to construct more lane miles for the same investment to the same or higher level of safety as today. Continuous improvements to design standards will be possible to respond to changes in driver and vehicle characteristics.

Benefits to Other Safety Data Users

The examples above demonstrate how an improved system could benefit the design community. However, there are a multitude of users of highway safety data—each with different but overlapping needs for information and analysis capabilities. The system proposed herein is similar in many respects to improvements being proposed by other users for other uses. The benefits described above in a design context will be similar for users in other contexts.

Improving the quality of crash, roadway, and other data will benefit users other than the design community. Some of the same safety data desired by designers are useful for traffic law enforcement, motor vehicle administration, education, trauma management, and so forth. This report focuses on the functions and activities of state design agencies; however, the same system is equally usable and beneficial to local agencies. Several of the current databases maintained by the federal government are built from data provided from states with little additional data review and editing. Improvements in coverage, consistency, and other dimensions of quality will also benefit these programs.

The system described herein is designed to serve highway design functions; however, many of its elements would be common to any advanced system to deliver useful information and decision support. Therefore, beyond considerations

Current Practice	Becomes	Improved Practice Using the New System
Extensive manual assembly of safety data tabulations from different offices within and outside the design agency, requiring many hundreds of staff hours	→	Direct access to a comprehensive data warehouse within a CADD/GIS environment
Manual inspection of hard copy of crash reports from microfilm record to correct coding errors	→	Pre-screened data minimizes errors, including proper location of crash, plus immediate access to digital images of crash reports within CADD/GIS environment
Labor-intensive translation of tabulations of key data into calculated fields and graphics using independent spreadsheets and graphics software into which data must be manually keyed	→	Integrated statistical routines, business graphics and advanced data-visualization software, including intelligent collision diagrams plotted on actual geometry and highway attribute time lines
Lack of historical traffic data and history of site geometry	→	Data warehouse with records of all available traffic counts and a continual, up-to-date history of physical attributes of the site
Lack of safety models and limited flexibility of data systems to provide support for positions taken regarding the hazards at the site and the effectiveness of proposed improvements	→	A suite of design analysis models to assess existing and proposed designs from a variety of perspectives, making it feasible to produce a documented and defendable estimate of safety impacts of alternatives
Support for decisions regarding data to use, analysis of it, conclusions to be drawn, and arriving at recommended improvements comes from staff or specialists	→	A central decision-support function within the system to provide the user with guidance at every step of the analysis
Decision tools which are applied are done manually	→	A suite of decision tools using the latest developments in decision science is directly accessible, with information generated by the system based upon the previous work of the designer

Figure 12. Examples of impact on safety analyses for a design project with implementation of the DDSS concept.

of improved data, many of the components of the proposed decision support system can prove useful to other safety analysts.

Development of the proposed system should not be approached as an independent activity of the design community. Much of the data collection and management aspects of the system will depend on a coordinated development program. Except for specific aspects of the system, the information delivery and decision support aspects of the system should also be done through a cooperative venture. Provisions for a safety management system in ISTEA included the intent to form strategic partnerships to improve safety data and management. The design community should be encouraged to take a very active part in implementing and expanding this effort.

The suggested subsystems will be expensive to implement. Major investments will have to be made in research, prototyping, infrastructure development, training, programming, operations, and maintenance. Cost-effectiveness of the system can be greatly enhanced by sharing costs across a wide a spectrum of users.

CHAPTER 4

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

The project findings have led to the basic conclusion that decisionmakers can have improved safety information to support highway design. To achieve this outcome, the highway design community has some important tasks to accomplish. The term "highway design community" includes those at the federal, state, and local levels of government who are responsible for defining the geometric attributes of the highway system. It includes those who serve these agencies either as consultants or in the performance of research for them. Therefore, the design community includes those who make and implement transportation policy and those who make decisions about investment in the highway system—system planners, traffic engineers, safety analysts, and highway designers. Through appropriate leadership, this broadly defined group should do as follows:

1. *Recognize the importance of the role of safety in making design decisions, the inadequacy of present methods for incorporating safety, and the need to improve and enhance methods for analyzing safety.*

The importance of safety is accepted by most at face value. However, the pressures of competing objectives, in the face of limited confidence in highway safety impact estimates, often relegates the role of safety considerations to a minor one compared with other factors. The reasons for this are often a function of a lack of quantitative safety information comparable in quality to other data such as construction costs. As a result, consideration of safety concerns is minimized. This concept is illustrated in Figure 13.

2. *Take an active role as part of the broader safety community* to do the following:
   a. Help define designers' requirements for safety data (including type, amount, and quality);
   b. Work with other users of safety data, in cooperation with collectors and managers of the data, to plan, design, finance, and implement systems useful for design purposes, as well as the wide range of other users.

Historically, the highway design community has not been an active member of that part of the larger safety community that deals with the collection and management of safety data. In some cases, those who collect and manage safety data needed by designers are not recognized as part of the safety community (e.g., maintenance sections). With the advent of the safety management system (SMS) concept, the need for the design community's participation is now more widely recognized. Designers, however, must recognize themselves that their active participation is needed to ensure that their needs are being properly reflected and that all stakeholders are involved.

3. *Begin to work on developing new ways of delivering information, using all the appropriate technology.*

In the past, data from information systems generally have not inspired great creativity, because much of the user's energy has been devoted to understanding and reformatting what is delivered to make it useful. Furthermore, many of the designers lack "graphic literacy." That is, they have limited ability to readily interpret graphics beyond the basic ones used in business. Users, therefore, are not readily able to form requests for improved graphic representations. Those who provide information must seek out new ways of displaying data, relying primarily on graphic depiction, and using new technology to make such data useful. A few examples have been suggested in this report.

4. *Better prescribe and promote proper approaches to analysis and decision making.*

Statistical and other appropriate analytical skills represent another area where knowledge and sophistication are limited among the users in the design community. Help is needed in defining proper approaches for analyses and in developing aids to resolve design problems and assist with decisions.

5. *Embark on an ambitious program to demonstrate and develop the decision support systems that are needed, once improved information is available that justifies their use.*

Many of the concepts of a decision support system are "foreign" to potential users of a DDSS. If a cooperative, comprehensive development effort is to be mounted, users and potential financiers of it must be able to see, firsthand, the potential.

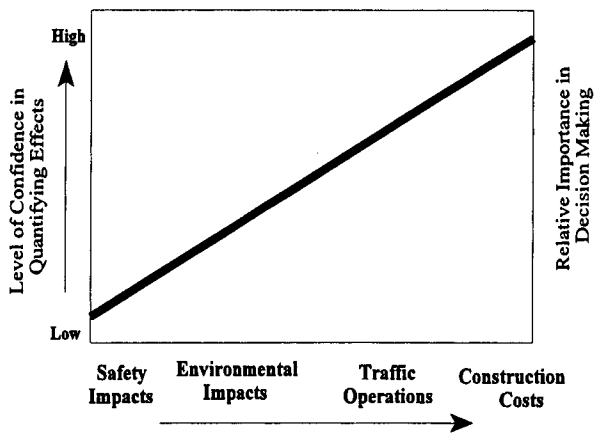

Figure 13. Relative role of safety in design decisions.

The FHWA has a major initiative underway to develop an IHSDM. This 10-year, multimillion dollar effort has the goal of developing a systematic approach for explicitly considering the safety implications of design decisions. The IHSDM will consist of five modules designed to operate within CADD and applicable to both new construction and reconstruction projects. Many of the proposed tools are extant, but need refining and integrating into the design environment that the IHSDM proposes.

As modules are completed and demonstrated, users will begin to see the potential for such a system. However, unless the broader decision support aspects are also addressed, as outlined in this report, users also may be confused by the profusion of models and information that is generated and put before them to deal with.

Although IHSDM continually is evolving, its present definition focuses primarily on analytical tools. This highlights the need for decision support tools identified in this NCHRP project, including the following:

- Providing the designer with improved methods for assembling and displaying the safety data that exist or shortly will be available from improved collection and management systems;
- Assisting designers in identifying underlying problems associated with the safety history at a site, including use of expert systems and appropriate statistical techniques;
- Creating a comprehensive decision support framework within which the improved data can be most effectively used;
- Developing a system that integrates the analytical and decision-making functions, for application throughout the entire design process; and
- Assisting the designer in documenting the results of the analysis and design work.

The commitment that IHSDM represents at the federal level further emphasizes the importance of providing quality safety data to users and doing it within an effective environment. Until the collection and management of safety data improve, sophisticated tools for assisting the designer, such as the IHSDM and a DDSS, will be limited in their applicability. In most cases, improvements can be achieved by altering management's approach to collecting and handling data along with technical improvements.

6. *Reexamine the institutional and organizational structure and environment to identify those barriers to positive change and begin to anticipate how organizational change must take place in order to maintain effective operations.*

Organizational and institutional barriers to change exist, as discussed in this report and as recognized in the design community. Although change may disrupt operations, the increasing role of technology in the operations of business and government dictates that new perspectives be developed and new policies and procedures be adopted.

Several initiatives already exist at the federal, state, and local levels to use technology to improve the quality of basic safety data needed by the safety community. However, needs also exist to do the following:

- Synthesize, at the national level, what is being learned;
- Widen the focus of improving the quality of crash data to include acquiring better data about physical, control, and traffic features of the highway;
- Integrate nontraditional safety data, such as maintenance activities, citizen comments, and pavement management files;
- Address the increased pressure on law enforcement to eliminate reporting of property-damage-only crashes;
- Overcome underlying resistance to change within many institutions, especially at the state level, including the adoption of new technologies; and
- Establish a comprehensive framework for system improvement within which new methods and technologies can operate.

From an organizational perspective, recognition is needed that the role of the designer is critical to improved highway safety and that the designer needs adequate data if that role is to be met. Implementation of a DDSS can reduce some of this separation between safety and design in that such a system would have safety aspects as a key component.

SYSTEM IMPLEMENTATION

Suggested Research

A comprehensive research and development effort is required to arrive at a DDSS. In many cases, it will involve combining the products of independent initiatives (e.g., IHSDM). The structuring and scheduling of this effort will itself require an extensive effort. A framework for overall

Title/Objective	Schedule and Budget
1. Develop New and Improved Methods for Displaying Safety Information to Support Design Decisions (Type 1)	
Demonstrate the feasibility and usefulness of improved safety information displays for achieving better consideration of safety in decisions on design projects. Specifically, develop graphic tools for displaying site crash, traffic, and physical history in a graphic manner within a CADD/GIS environment.	$175,000 24 months
2. Assess Tools and Techniques for Improving Accuracy of Reported Crash Locations (Type 2)	
Recommend one or more systems for reporting agencies to use to accurately and precisely report the location of virtually all crashes being entered into the safety database.	$50,000 12 months
3. Assess the Potential Role for Safety Audits in a DDSS (Type 2)	
Identify the potential role of safety audits in a design decision support system. Secondarily, assess the concept vis-a-vis a potential role to collate and synthesize the results of several analytical models (as planned for the IHSDM) and other information.	$50,000 12 months
4. Assess the Usefulness of the Current State-of-the-Art of Decision Support Systems for the DDSS (Type 2)	
Identify commercially available decision support systems that may be used to create an initial implementation of the DDSS module. As a secondary objective, arrive at a detailed definition of the specifications for a decision-support module for the DDSS, including definition of a comprehensive research and development program.	$150,000 24 months
5. Develop and Demonstrate Improved Methods for Safety Data Collection (Type 1)	
Determine the feasibility of using specific new techniques and technologies to improve the quality of crash data. Address human factors and cost-effectiveness issues.	$250,000 30 months
6. Demonstrate the Means to Collect, Manage, and Use New Sources of Safety Data (Type 1)	
Demonstrate and evaluate the application of two existing types of safety data not currently employed by most safety analysts involved in design or design-related work. These are supplemental crash investigation reports and digital images of highways.	$100,000 12 months

Figure 14. Proposed initial research and development program for the DDSS.

system implementation appears in Appendix J. There are, however, some specific immediate development and demonstration projects that can provide a basis for proceeding with a more comprehensive program.

Figure 14 depicts these projects. Some are discussed in greater detail in the following sections. Individual project statements appear in Appendix K. Figure 14 shows that most of the initial development and demonstration activities can be funded for a relatively low cost and completed over periods of 24 months or less.

The projects are of three basic types:

1. **Development and demonstration.** Aspects of the proposed system can be developed to provide an immediate demonstration of the type of concepts being proposed. The purpose of the work would be to enhance the reality of what is conceived and to provide early products that the profession can use, even before achieving full-scale implementation of the desired system.
2. **Evaluation.** More detailed evaluation of tools, technologies, and methods that may be included within a DDSS is needed. This will allow determination of the extent to which current, or emerging, state-of-the-art tools and technologies are applicable and the effort that may be required to totally develop system elements independently.
3. **Long-range planning.** The system envisioned for the DDSS will not suddenly appear in finished form one day—it will evolve as various elements are developed and successively integrated into the design process. This process will include merging the results of more than one independent initiative. Some of the initial development and demonstration should be dedicated to arriving at a comprehensive view of how this integration may be achieved. Long-range planning should include defining a structure for the system, with elements defined such that they facilitate dividing the effort into a series of workable projects to be completed in a logical sequence over an extended period.

Implementation Guidelines

Many of the elements of the proposed system are of interest to those outside the design community as well. Therefore, research, development, and demonstration efforts may already

be programmed for some of the recommended initiatives. For example, in addition to their study of crash-reporting technologies mentioned above, FHWA has begun to consider safety audit methods.

Successful completion of Project 1 (development and demonstration) and Project 2 (evaluation) will result in early products that will demonstrate to the design community the potential of the proposed DDSS. The tools that would be identified and developed under those projects can be put to immediate use within many existing safety analysis systems. This would result in an early return on the investment while setting the stage for the future.

CLOSURE

Successful implementation of this program will require strong central leadership and a partnership among many state agencies, as well as federal agencies and national organizations. If duplication and incompatibility of system elements are to be avoided and efficiency of time and resources is to be encouraged, an umbrella entity under which the stakeholders and funding agencies can work together effectively must be formed. One of the first activities toward creating a DDSS will involve dealing with this issue.

APPENDIX A

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APPENDIX B

ANNOTATED BIBLIOGRAPHY

Abkowitz, Mark *et al.* "Adaption of Geographic Information Systems to Highway Management." *Journal of Transportation Engineering* 116, no. 13 (May 1990) 310–327.

The advent of geographic information systems (GIS) has created a technology with considerable potential for achieving dramatic gains in efficiency and productivity for a multitude of traditional and innovative highway management applications. However, to capitalize on GIS technology, it will be necessary for highway agencies to adapt the way in which they collect, store, and utilize data, as well as undergo fundamental changes in how they carry out technical responsibilities. This paper addresses these considerations through a study of: (1) Highway management applications that can benefit from adaptation to GIS; (2) key GIS concepts affecting highway transportation; and (3) issues affecting GIS design and implementation within and between highway agencies. The results of this study are reported in terms of establishing guidelines for successfully achieving full GIS adaptation to highway management.

"Accident-Analysis Software Needs Identified." *Urban Transportation Monitor* 4, no. 10 (25 May 1990) 1, 10–11.

Need-appropriate software for collision diagramming and presenting data in sorted fashion. When examining software, consider interface between database and CAD. Less than 50 percent of those surveyed performed conflict analysis, but those who did found their software acceptable for these purposes. Most software is developed in-house with particular emphasis on providing high-hazard locations. Frequency of crashes generally used to identify segments, and rates based on entering vehicles used to identify intersections.

Aden, David. "Traffic Jams No Longer Mean Radio Jams." *Government Technology* 8, no. 8 (August 1995) 18–19. Allen, R., Theodore J. Wade, and David H. Klyde. "Application of Vehicle Dynamic Modeling to Interactive Highway Safety Design." Paper presented at the Transportation Research Board, Washington, D.C., 22 January 1995.

This paper describes the application of vehicle dynamic modeling to highway safety design. This concept is intended to permit highway engineers to test designs by computer simulation of vehicle encounters with roadway geometric. The procedures will allow running a vehicle through design alternatives, provide metrics of vehicle performance, and permit computer graphics visualization of the vehicle/roadway encounter. The overall design concept is described, and examples are given of vehicle dynamics.

American National Standards Institute. *State's Model Motorist Data Base, Data Element Dictionary for Traffic Records System, 2nd Edition (ANSI D20.1).* Arlington, VA: American Association of Motor Vehicle Administrators, October 1993.

A recommendation for standard fields and coding to be used by police in recording traffic crash data.

Andreassen, D. *A Guide to the Use of Road Accident Cost Data in Project Evaluation and Planning.* Report 226. Victoria, Australia: Australian Road Research Board, July 1992.

The accident costs that have been available for Australia over the last two decades have only been presented as a cost per person by Abbreviated Injury Score or as the cost of a 'fatal' accident, the cost of a 'non-fatal' accident, and the cost of a 'non-injury' accident. These latter costs have been in error, because they were derived from a distribution of accident 'severity' and not from a distribution of the casualty class of persons. They were also in error because of a misapplication of the person casualty costs by counting only those killed in fatal accidents and only one level of casualty in the non-fatal injury accidents. These costs by 'accident severity level' understate the value of the accident savings for particular treatments. This also results in the safety benefits being only a small part of the overall benefits of a road improvement program. The aim of the project, entitled "Accident Costs for Projected Planning and Evaluation," was to produce standardized costs per accident for a range of accident types. Costs have been estimated for 19 accident types in urban and rural areas. Standardized costs per person for five casualty classes were also determined as an integral state for accident-type costs. This guide has been produced as a short 'how to' manual to show how to do an analysis of the safety benefits, disabilities, and costs associated with the use of particular safety countermeasures. Worked examples of benefit-cost analysis are given for counter measures that reduce accident frequency and countermeasures that modify injury severity. A checklist is provided for use prior to evaluation, the effect of countermeasures or particular variables is tabled, and a way is given to estimate the proportion of accidents likely to be affected by the countermeasure. The use of the accident-type methods described in the Guide is more realistic for evaluation and has been shown to give significantly higher Benefit Cost

Ratios and Net Present Values than the previous accident-severity techniques.

Andreassen, D. C., and J. N. Evangelou. "The Quality of Accident Data." *Proceedings, 15th Annual Conference*. 167–178. Australia: Australian Road Research Board, August 1990.

Published national accident statistics are an aggregation of the data from each State and Territory in Australia. In order to make use of this data, it is necessary to believe that the data supplied from each State are the result of identical, or at least similar, procedures followed by the police in each State to interpret and record the information received about each reported accident. If different views/interpretations are used in each State to define the severity of a road accident, even the so-called reliable indicator ('road deaths') will make for somewhat dubious interstate comparisons. This paper discusses the situation in each State with regard to differences in procedures and differences in interpretations, what needs to be changed, and how far we are from adopting the Common Core data items endorsed by ATAC in 1977. Road safety cannot look to any improvement without having accident data that are both sensible and reliable. To achieve this will require greater clarity in the format and wording of report forms and a reasonably assured uniformity of interpretation from State to State. Uniformity may be achieved by producing, for national use, a Model Guideline for the collection and classification of traffic accidents, encompassing all the necessary definitions and interpretations. Authors do not make reference to vast body of literature related to quality of crash data that has been presented at numerous forums (e.g., Hauer & Hakkert, referenced elsewhere).

Arberg, Lars. "Driver Behavior at Flashing-Light, Rail-Highways Crossings." *Accident Analysis and Prevention* 20, no. 1 (February 1988) 59–65.

Address studies are given of how drivers behaved at railroad crossing when signals were flashing to indicate the approach of a train. Different behaviors are documented and analyzed.

Armour, A. *et al. Study of Single Vehicle Rural Accidents - Accident Data Report*. GR/89/4. Victoria, Australia: Road Traffic Authority, April 1989.

The Victoria Study of single vehicle rural accidents was a joint initiative of the Victorian Road Traffic and Construction Authorities and the Transport Accident Commission. The aim of the project was to increase understanding of single vehicle accidents, particularly the roles of roadside objects, vehicle speed, and driver fatigue in accidents. The factors identified as most commonly contributing to accidents were trees close to the traffic lanes and the presence of unsealed shoulders. Driver fatigue was also identified as a major problem. Volume I examines the analysis of crash reports as they identified roadside related causal factors. A total of 155 crashes involving either a fatality or hospitalized injury were studied; 110 involved a roadside object including trees, bridge abutments, and culvert head walls. Roadside objects were considered to result in increased severity in 27 percent of crashes studied. Other geometric features did not play as important a role. The report presents detailed tables relating various factors to death and serious injury.

Armour, A. *et al. Study of Single Vehicle Rural Accidents Road and Roadside Report*. GR/89/6. Victoria, Australia: Road Traffic Authority, December 1989.

Another part of the study of single vehicle rural crashes, the abstract for which is given in a previous part [see Armour et al., April 1989].

Balbissi, Adli H. "Role of Road User and Roadway Geometrics in Road Accidents in Jordan." *Transportation Research Record 1270*. 42–45. Washington, DC: Transportation Research Board, 1990.

Jordan's road network has been one of the fastest growing systems in the area and promises to continue developing in the years to come. In order to continue this road development, the state of Jordan is searching for means to improve road safety and management practices. Following numerous requests made by public officials for aid and guidance in the road safety field, several research teams were formed. The aim of this team is to undertake research in Jordan with a view to establishing the nature and extent of its traffic accident problems, and in the longer term to assess the effectiveness of remedial measures. Some of the major findings of these research teams are described. Special emphasis is given to the effect of road users and geometrics on road accidents. Road users were found to be responsible for about 95 percent of all accidents.

Basha, Paul E., and Steve L. Ramsey. "A Methodology for Comparing Accident Rates." *ITE Journal* (May 1993) 30–35.

Methods normally employed by engineers is to compute crash rates, an average, and standard deviation, then to select for further reviews all locations where the rates exceed a standard (e.g., 2 s.d). The use of a mean assumes that crash rates are distributed normally, which may not be the case. Author suggests a different approach based on the median which does not require normalcy. Compute the 25th, 50th (median), and 75th percentile. This is shown as a box. Forming a Box and Whiskers diagram, extend the whiskers from each end of the box to the extreme rates and compute break points. The author suggests an 'inner fence' to lie at the 75th percentile plus 1.5 times the difference between the 75th percentile and 25th percentile rates. A second 'outer fence' is placed at 2.5 times the difference. Generally, it is only necessary to identify fences which exceed the 75th percentile. This method provides a better method of comparing changes over time. Improvement in the overall performance of all segments or intersections is seen when the box shrinks in size and the 75th percentile decreases. More importantly, changes at specific locations can be plotted clearly and are obvious

when compared to the box. Investigate carefully all rates that exceed the outer fence. Establish what issues are causing the high numbers. Those rates lying between the inner and outer fence should be examined for general factors (e.g., type of collision). Anything lying below the inner fence can be ignored or examined briefly depending on how close it is to the fence itself.

Bayley, J. M., and C. B. Uber. "A Comprehensive Program to Improve Road Safety at Railway Level Crossings." *Proceedings, 15th Annual Conference.* 217–234. Australia: Australian Road Research Board, August 1990.

Earlier programs to install flashing lights or boom barrier protection at crossings in Victoria have been effective in reducing road/rail accidents. However, fewer installations have been provided in the more recent years. It is time for Victoria to consider overseas research and experience and to implement a comprehensive program which would utilize research on road user behavior to assist in selection of low cost alternative solutions to improve road safety without necessarily upgrading the level of road safety protection. Some portions of the comprehensive program are actions which could aid safety at all crossings, such as placing strobe lights on locomotives, reflectors on freight cars, development of pentagonal reflectors, and developing new standards for traffic control devices for level crossings. Need to identify other 'black spots' using criteria similar to that used for initial installation of barriers. Also need ongoing research to identify causes of crashes and effectiveness of preventive measures. Article considers other countermeasures but presents no evaluations of effectiveness. Numerous references to assessments of effectiveness done during mid-1980s.

Belanger, Carl. "Estimation of Safety of Four-Legged Unsignalized Intersections." *Transportation Research Record 1467.* 23–29. Washington, DC: Transportation Research Board, 1994.

In this study, empirical Bayesian methods were applied to the estimation of the safety of four-legged unsignalized intersections. This application can be described as a two-step process. First, multivariate models were developed to estimate the number of accidents from various flow functions at these intersections. The best model was obtained from the product of major and minor flows, raised to a power. Attempts were made to develop models for specific patterns of collisions and to incorporate variables other than traffic flow functions to these models. The modeling results were then combined with the accident count of a four-legged unsignalized intersection to estimate its safety. Results were used to identify black spot location to estimate its safety and to evaluate the effects of interventions more accurately.

Benekohal, Rahim F. "Methods for Estimating Accident Reductions from Highway Improvements." *ITE 1991 Compendium of Technical Papers.* 419–423. Washington, DC: Institute for Transportation Engineers, 1991.

Reduction in the number of accidents resulting from highway improvements is commonly estimated using either an accident prediction model or a before-and-after study. When the two methods do not yield the same reductions, the highway improvement evaluation results depend on the study approach used. This study utilized both methods to assess the effect of the approach used on the estimated reduction in the number of accidents on two-lane rural highways. Accident data for two years after the improvements were collected for 51 sites with a total length of 349 miles. Accident frequency was correlated to traffic volume and roadway geometry. Linear prediction models were found to express the relationship better than the multiplicative models when traffic volume was under 5000 vehicles per day. However, the linear prediction models yielded accident reductions 1.4 to 2.1 times less than those from the before-and-after study with control sites.

Berg, W. D., J. Choi, and E. J. Kuipers. "Development of Highway Alignment Information from Photolog Data." *Transportation Research Record 1239.* 54–61. Washington, DC: Transportation Research Board, 1989.

The Wisconsin Department of Transportation operates an instrumented vehicle that collects both photolog and digitized geometric data on roadway bearing, grade, and cross slope. These data are recorded every 0.01 mile. The objective of the research was to develop the methodology and computer software necessary to transform the digitized roadway data into a highway alignment database for use in inventory studies, deficiency analyses, and preliminary design studies. The software created locates horizontal curves and provides estimates of the radius, length, super elevation, and maximum recommended speed. A vertical profile can be plotted, and the location of segments with either stopping or passing sight distance restrictions due to horizontal and vertical alignment are identified. The software was tested and validated by using as-built plan and profile data for a case-study highway. Originally prepared as a special report to Wisconsin Department of Transportation.

Berg, William D. *et al. Development of a Computerized Deficiency Analysis Methodology for the WISDOT Highway Datalog System.* (unpublished). Madison, WI: University of Wisconsin - Madison, January 1992.

Wisconsin DOT uses a photolog vehicle instrumented to capture alignment data at 0.01 mile intervals. Computer programs convert the data. These data are integrated with FHWA Highway Investment Analysis Package (HAIP) to help produce input for benefit-cost analyses. Used photolog and HAIP software to develop safety deficiency assessment. Step could preclude need to obtain and review plan and profile drawings. Developed computer software which integrates

the photolog and HAIP output. Demonstrates some output from the safety deficiency program.

Bhesania, Russi P. "Using Accident Statistics and Characteristics to Improve Safety." *ITE Journal* 61, no. 3 (March 1991) 37–42.

Examined crashes occurring at intersections, mid-block, and with pedestrians using 1989 Kansas City, MO data. Reiterated previous findings related to location and types of collision (e.g., signalized intersections had crashes at 4 times no-signalized intersections). Most crashes are at right angles. Author recommends that locations be plotted, frequency of occurrence versus cumulative percent of locations involved. Take those locations exceeding 85 percent and then perform rate analyses. For intersection crashes, the 85 percentile lies at 10 crashes or more and represents more than 300 intersections.

Blair, John D. "Microcomputer Traffic Records System for Accident Analysis." *Microcomputer Applications in Transportation III: Proceedings of the International Conference on Microcomputers in Transportation.* 469–478. New York: American Society of Civil Engineers, 1990.

Blue, Douglas W., and Bohdan T. Kulakowski. "Effects of Horizontal-Curve Transition Design on Truck Roll Stability." *Journal of Transportation Engineering* 117, no. 1 (February 1991) 91–102.

This article provides information that will facilitate the design of roads that are safer for heavy trucks, which have a greater tendency to roll over than passenger cars. The roll performance of tractor-semitrailer trucks on horizontal curves with three different types of transitions is investigated using computer simulation, and the results are used to develop guidelines for horizontal-curve transition design. The roll dynamics of a truck traveling on a transition and a superelevated curve are described, and the effect of superelevation on the rollover threshold of tractor-semitrailer trucks is also discussed. Three evaluation parameters (roll stability margin, acceleration overshoot, and critical speed) are proposed and used in evaluating different transition types. Three types of transition are investigated: one in which two-thirds of the maximum superelevation is developed before the start of the curve; one in which the superelevation is fully developed at the start of the curve; and one in which superelevation is developed in a short spiral section. A test matrix consisting of different truck speeds, different radius curves, and different transitions is used. The spiral transition is shown to be the most desirable type of transition.

Bonneson, James A., and Joel W. Fitts. "Traffic Data Collection Using Video-Based Systems." *Transportation Research Record 1477.* 31–40. Washington, D.C: Transportation Research Board, 1995.

Two of the principal elements in the design of a traffic data collection plan are event measurement accuracy and precision. Bias in the measurements can affect their accuracy whereas the lack of precision in measurement can increase the minimum sample size. The objective of this paper is to describe the sources of bias and variability in the measurement of time-based traffic events using video recording/play back systems. Equations are provided that describe these sources. These equations can be used to estimate the adjustment needed to remove bias from the recorded data and to estimate the standard deviation of the measurement process. Time-based traffic events, such as headway, speed, and travel time, can be accurately and precisely measured using video tape recording/playback systems. The methods of extracting the individual traffic events include manual extraction using a frame-by-frame analysis and automated extraction using a video imaging system to analyze the tape during playback at 'normal' speed. The minimum headway that can be reliably detected by the automated method ranges from 0.5 to 1.7 seconds, depending on vehicle speed. There are several sources of error variability in the measurement of time-based traffic events when using video systems. This variability increases the chance of making a large error in the measurement of an individual event time, and it increases the sample size needed to estimate the mean event time. The manual method of data extraction is found to have a lower variability than the automated method.

Bonneson, James A., and Patrick T. McCoy. "Estimation of Safety at Two-Way Stop-Controlled Intersections on Rural Highways." *Transportation Research Record 1401.* 83–89. Washington, DC: Transportation Research Board, 1993.

Bowman, Brian L., and Joseph Hummer. "Data Validity Barriers to Determining Magnitude of Large Truck Accidents." *Traffic Quarterly* 47, no. 1 (January 1993) 39–60.

A review of literature and research related to truck crashes with the view that most of the literature has drawn conclusions based on misleading or inappropriate analysis. A recurring problem is overestimation based on exposure using traffic components which do not reflect the actual mix of trucks and other vehicles because of averaging; lack of randomness in selecting sites to study and using sites as 'representative,' obvious conclusions (e.g., a crash involving a heavy truck and small car is more likely to result in a fatality than a crash between two small cars), and using an incomplete and biased data source such as the Motor Carrier Management Information System operated by the Interstate Commerce Commission. In addition, many exposure bases are dependent on 'short-count' volume studies which are not adequate to record true volumes of trucks, particularly when dividing trucks into classes. More importantly, use of vehicle miles can be misleading where exposure is time dependent. For example, the exposure in time is the same when driving 10 miles at 30 mph

as for driving 20 miles at 60 mph; yet, the vehicle miles driven are twice as many at 60 mph. One form of study known as 'quasi-induced' exposure based on 'at-fault' judgements by investigating police has shown some promise for a more adequate assessment of the role played by truck crashes. However, this method suffers from biases of the police who are 'finding fault.'

Bowman, Brian L., and Robert L. Vecellio. "Effect of Urban and Suburban Median Types on Both Vehicular and Pedestrian Safety." *Transportation Research Record 1445*. 169–176. Washington, DC: Transportation Research Board, 1994.

Urban and suburban traffic engineers have the difficult task of providing safe roadway cross sections for all types of uses. The major difficulty arises at most central business districts and at many suburban locations because of relatively high volumes of pedestrians attempting to cross roadways with minimum available traffic gaps. This is due to differences in operating characteristics between vehicles and pedestrians. Measures to increase vehicular capacity on arterials often result in potential hazards to pedestrians. It has long been recognized that medians are an effective method of increasing vehicular safety and capacity on urban and suburban arterials. Also medians are generally considered to be beneficial for pedestrian safety and operations, but their actual effects are unknown. The results of a study sponsored by FHWA on the impact of median types on the safety of vehicles and pedestrians are presented. The study included the analysis of 32,894 vehicular and 1,012 pedestrian accidents occurring in three cities on arterials with the following median types: (a) raised, (b) flush or two-way left-turn, and (c) no existing median (undivided).

Brahimi, F., and R. Ashworth. "A Theoretical Model for the Permissive Right-Turn Capacity of Shared Lanes with an Opposed Flow at Traffic Signals." *Mathematics in Transport Planning and Control (Proceedings)*. 69–80. Oxford, England: Clarendon Press, 1992.

This paper presents a theoretical model for the calculation of shared lane capacity (i.e., lanes with a mixture of straight ahead and right-turning vehicles) with an opposed flow at traffic signal controlled intersections. The model is a development of the Swedish Capacity Manual and the US 1985 Highway Capacity Manual methods and assumes binomial distribution of direction assignments in the subject lane, a random arrival pattern on the opposing approach, and a step function for the gap acceptance requirement of right-turners. The model also accounts for any number of spaces available for right-turners to queue within the intersections without blocking the lane for following vehicles. Signal settings are assumed to operate on a fixed-time basis and results are presented to illustrate the effects of different green time settings and waiting spaces on shared lane capacity. The model was tested against field data collected at two such intersection entries in the Sheffield urban area. The calculated capacities were found to compare well with those observed in reality; statistical analysis indicating that the differences between observed and calculated values were not significant at the 95% confidence level. These results compare favorably with those obtained by other theoretical models, such as the 1985 HCM method and the TRRL RR67 procedure.

Bretherton, W. Martin. "Computerizing Records for a Local Government—Past, Present, and Future." *Compendium of Technical Papers*. 483–487. Washington, DC: Institute of Transportation Engineers, 1989.

Brogan, James D., and Jerome W. Hall. "Using Accident Records to Prioritize Roadside Obstacle Improvements in New Mexico." *Transportation Research Report 1047*. 10–17. Washington, DC: Transportation Research Board, 1985.

A method is described for using a critical accident rate to select and prioritize sections for improvement. The authors use standard crash files, and the roadway inventory file to correlate with traffic data for deriving crash rates. However, it is noted that it is difficult to determine whether the same objects are being struck repeatedly, using the roadway inventory file. Therefore, it was found that the hard copy of the crash report had to be reviewed, as well as the photolog. In many cases, it was also necessary to make field evaluations, before concluding on the appropriateness of listing a section for action. The lack of adequate data made this effort laborious and time consuming.

Broome, Michael. "The Role of Environmental Audit in Highway Design." *Proceedings, PTRC Transportation, Highways, and Planning, Summer Annual Meeting*. 1–5. Manchester, England: University of Manchester, September 1992.

Although the normal assumption is that the highway must carry traffic safely and swiftly, there is a growing need to consider effect of highway on environment. Though not addressed directly by author, there is a need to balance environmental concerns with highway design; it can be dictated by environmental studies resulting in inefficient or unsafe elements. Problem is that environmental statements are not written in technical terms. Techniques not available effectively to quantify and measure most environmental aspects. Good examples are attempts to identify both noise and air pollution. Additional problem is that environmental effects at a local level must be balanced with those over a larger area. Author provides steps in performing environmental audit. Discusses the different forms of audits, customers, and resources required. Lack of qualified personnel to perform audits remains a problem.

Brown, Bruce, Celine Farley, and Michelline Forgues. "Identification of Dangerous Highway Locations: Results of Community Health Department Study in Quebec." *Transportation Research Record 1376*. 78–85. Washington, DC: Transportation Research Board, 1992.

Dangerous highway locations on numbered highways within the territory of one community health department are identified. Three sources of information are used: police accident reports, systematic inspection of all numbered highways, and a community survey of municipalities, police, and health service providers. The locations of all police-reported fatal and serious-injury accidents were reviewed and corrected, and corrections were submitted to the reporting jurisdiction; this resulted in a 20 percent increase in the number of these reports attributed to numbered highways. The initial police-reported data included 11,538 accidents with and without victims occurring on the 271 km of numbered highways in the territory between 1984 and 1987. A weighing system based on the severity of injury for each police-reported injury was used in the initial screening process; the influence of differing weighting schedules using corrected and uncorrected location data is presented in a matrix. Weighted injury frequencies per unit distance and weighted injury rates per 100 million vehicle-km are presented for all sites and for all numbered highway segments. Priority sites are ranked considering injury frequencies and injury rates. The convergence of identification by police-reported data, by highway inventory, and by community reporting is presented. The 28 priority sites retained for further study cover about 6 percent of the numbered highways in the territory but account for 53 percent of deaths, 30 percent of serious injuries, and 32 percent of minor injuries from accidents reported by police.

Brown, David B., Ken Bradley, and Dennis Weldy. "Keeping Score Lowers Toll: New Computer Record System Quickly Highlights Death Traps." *Traffic Safety* 90, no. 2 (March 1990) 23–26.

Describes improved database system built for Auburn, AL. Allows users to obtain data in various tabular forms and to select elements to be presented. Menu driven system. Provides both bi-viriate and univariate statistics. Article stresses how user should examine data.

Brown, David B., Robert Bufin, and William Deason. "Allocating Highway Safety Funds." *Transportation Research Record 1270*. 85–88. Washington, DC: Transportation Research Board, 1990.

Productivity in many governmental agencies can be greatly increased by the application of optimization techniques. As these techniques progress, it is important to keep those agencies who are using them up-to-date with the most recent innovations. Presented is an update of a highway safety application, progressing over 15 years, from the use of dynamic programming to a branch-and-bound technique. The branch-and-bound technique is faster, can handle larger sets of project data, and does not suffer from round-off errors as did the dynamic programming technique. These features have enabled the total available funds from categorical highway safety grants to be allocated to produce the maximum benefit in terms of estimated savings of lives, injuries, and property damage.

Brown, David B., and Carolyn L. McCreary. "Implementing a Distributed Responsibility Approach to Improving Data Quality." *Transportation Research Record 1318*. 83–90. Washington, DC: Transportation Research Board, 1991.

An approach to improving data quality that is based on the concept of distributed responsibility is presented. This concept requires a direct distribution of data benefits throughout the data-responsible organizations. Premises on data quality are presented to formulate the problem so that the concept of distributed responsibility can be understood. Several accident data systems are discussed as examples of distributed systems, but proposals for continued development of this concept are strongly encouraged.

Brude, Ulf, and Jorgen Larsson. "The Use of Prediction Models for Estimating Effects Due to Regression-to-the-Mean in Road Accident Data." *Accident Analysis and Prevention* 20, no. 4 (August 1988) 299–310.

In recent years, various methods have been proposed for estimating the true accident level (i.e., the expected number of accidents m when a total of x accidents have been observed at a junction, road section, etc., during a certain period). One such method has been named the Empirical Bayesian Method (EB method). A description is given of a variant of the EB method utilizing prediction models for the number of accidents. Input data to the prediction models may consist, for example, of traffic flows in a junction. According to empirical comparisons of accidents in junctions, this variant of the EB method may be preferable in certain cases to the conventional EB method. However, it has not yet been determined how this variant of the EB method should generally take into account the precision of the prediction models. This means, for example, that in a nonexperimental before-and-after study of the effect of a particular action, varying results may be obtained according to the assumptions made concerning the precision of the prediction model.

CADRE Task Force. *National Safety Council CADRE - Critical Automated Data Elements for Highway Safety Analysis*. Chicago, IL: National Safety Council, 30 June 1991.

Recommends specific fields that should be included on all PCRs. These recommendations are designed to provide a basic, but critical, set of data which can be retrieved and used by traffic safety personnel and highway engineers to identify possible contributions to crashes and crash injuries.

Campbell, B. J. *The Use of State Accident Data for Road Safety Research*. Chapel Hill, NC: University of North Carolina Highway Safety Research Center, 1988.

This report examines the value of data from individual state crash databases in use for identifying national roadway safety issues.

Capelle, Russel B. *Planning and Managing Intermodal Transportation Systems: A Guide to ISTEA Requirements.* DOT-T-95-03. Washington, DC: Federal Highway Administration, November 1994.

This guidebook is designed to be a hands-on, planner-friendly document that answers hard questions about intermodal management system planning in practice.

Carney, John F. III, and Kenneth S. Opiela. "Roadside Safety Issues." *Transportation Research Circular Number 435.* Washington, DC: Transportation Research Board, January 1995.

Limitations included: not identifying which side of the road the vehicle leaves, unreported crashes (which varies by type of object struck, improper coding, incorrect use of nomenclature, and lack of detail, inaccurate location coding, inadequate linkage between crash and roadway data, and lack of detail regarding sequence of events). This is a report about a workshop conducted August 11–13, 1994 to discuss the current status of roadside safety research and explore new approaches and methods that could produce safety benefits in the coming decade. Included were prepared papers and breakout group findings. One of the groups addressed data needs. Limitations of police crash data were identified.

Carr, D. H., J. J. Curtin, and P. E. Dorvel. *Clear Zone for Local Agencies.* RD 194.1. Bothell, WA: CENTRAC, September 1989.

Review of nationwide clear-zone practices pointed to a need for a set of standard clear-zone guidelines or standards. Such are needed specifically for low-volume, low-speed facilities.

Casavant, Ken L., and Jerry Lenzi. "An Economic Evaluation of the Fee and Fine Structure for Overloaded Trucks in Washington." *Traffic Quarterly* 47, no. 2 (April 1993) 281–294.

Studies have shown that overloading trucks reduces the costs to the hauler by up to 19 percent. This incorporates the likelihood of a fine being levied. On the other hand, these savings can be offset quickly if fines are sufficiently high. More importantly, the fines need to be high enough that even given the likelihood of a fine being levied, the average cost will offset the savings to all haulers. The need to offset the savings arises from the substantial increases in pavement damage which results from overweight trucks. Such damage occurs to the 4th power of the excess axle loadings. Authors recommend a fee and fine structure that more accurately reflects (for the State of Washington) the estimated costs of pavement damage resulting from various levels of overloading. More importantly, enough of the fine must return to the road fund to be used for roadway reconstruction.

Catchpole, J. E. "Road Design and Fatal Accidents." *Proceedings, 15th Annual Conference.* 199–215. Australia: Australian Road Research Board, August 1990.

This paper outlines the first stage of an investigation by ARRB of the role of road and environment features in fatal accidents. This initial stage consisted principally of summarizing the data collected on ARRB's Fatal Accident Form and stored in the Fatal Accident Database. The number of features examined in this first stage was very large, and it is only possible to present a subset of the results here. Tables of site data for South Australian urban and rural fatal accidents from 1983 to 1987 are presented, and various difficulties in the interpretation of these tables are discussed. Examination of supplementary information such as sketch plans and photographs supplied with Fatal Accident Report Forms revealed that loss of control on unsealed shoulders is a substantial problem in rural driving. This problem is known to have contributed to at least 19 percent of single vehicle accidents on sealed roads with unsealed shoulders, but the true figure is probably considerably higher. It is concluded that the Fatal Accident Report Form provides valuable data for the investigation of the role of road and environment factors in fatal accidents, and that such data could not be supplied by other methods. In the second stage of the investigation, the site data held in the Fatal Accident Database will be combined with the driver and vehicle data contained in state accident databases. This will allow greater disaggregation of accidents and the linking of particular types of accidents with particular road and environmental conditions.

Chang, Edmond Chi-Ping. "Interactive Intersection Design Using an Expert Systems Approach." *Transportation Research Record 1239.* 10–16. Washington, DC: Transportation Research Board, 1989.

The development of 'expert systems' for microcomputer applications has received increasing attention in the transportation engineering field. Expert systems are computer programs that include simulations of the logical reasoning and problem-solving processes of human experts for specific applications. Proper implementation of this concept offers a possible means to effectively use the specific knowledge and experience of recognized professionals, efficiently use limited highway resources and revenue, and provide safe, efficient transportation programs. The major advantage of expert systems is that they permit specific human knowledge used in the decision-making process to be systematically examined, organized, and applied to particular engineering problems. During the typical intersection design process, highway engineers make many decisions concerning the operational effectiveness and trade-offs among a number of design factors. These important decisions may be bounded by either the planning budget, the potential total project costs, the maximum lane width of each typical highway lane, or the potential traffic demand volumes. This study illustrates the prototype applications of expert system design and LISP programming in the highway design

process using the AutoCAD package, AutoLISP, a version of LISP supported by AutoCAD, to create a small-scale expert system to interface with the normal drawing functions. This study demonstrates the feasibility of implementing built-in functions of the AutoCAD system through AutoLISP programs to assist end users in completing the decision making for potential highway design applications.

Choueiri, Elias M., R. Lamm, J. H. Kloeckner, and T. Mailaender. "Safety Aspects of Individual Design Elements and Their Interactions on Two-lane Highways: International Perspective." *Transportation Research Record 1445*. 34–46. Washington, DC: Transportation Research Board, 1994.

The results of an extensive literature review of the safety performances of low- and intermediate-traffic volume, two-lane rural highways are presented. The effects on traffic safety, as measured by accident rates, of pavement width, radius of curve/degree of curve, gradient, sight distance, traffic volume, and design speed on curved sections of two-lane rural highways are covered. The following are some of the main findings. There is a distinct tendency for accidents to decrease with increasing pavement width up to about 7.5 m (25 ft). There exists a negative relationship between radius of curve and accident rate. The sharper the radius of curve, the higher the number of run-off-the-road accidents. Curves that dictate a significant change in operating speeds and that cause nonhomogeneity in road characteristics are especially dangerous. The most successful parameter in explaining the variability in accident rates was degree of curve (United States) or curvature change rate (Europe). Gradients of up to about 6 percent have a relatively small effect on the accident rate. A sharp increase in the accident rate was noted on grades of more than 6 percent. There exists a negative relationship between available sight distance and accident risk. However, other influencing parameters, such as wide pavements and gentle radii of curve, might also play a part in the observed positive effect of sufficient sight distances on the accident situation. For narrow road sections, an increase in sight distance could favorably affect traffic safety. A negative relationship between traffic volume and road traffic accidents was established. Run-off-the-road accidents were found to decrease with increasing average annual daily traffic up to 10,000 vehicles per day. Recent investigations reported a U-shaped distribution between accident rate and traffic volume. An accident rate of 2.0 accidents per 10^6 vehicle km (3.2 accidents per 10^6 vehicle mi) was proposed as a breakpoint between levels of safety and non-safety. This breakpoint was derived from relationships between single design parameters. Limiting values for a number of design parameters are also proposed. If these limiting values were exceeded, the proposed breakpoint, in relation to the accident rate, would be exceeded.

"CHP Computerizes Its Front Lines." *Government Technology* 8, no. 10 (October 1995) 14–15.

Cirillo, Julie Anna. *Safety Effectiveness of Highway Design Features; Volume I: Access Control.* RD 91-044. Washington, DC: Federal Highway Administration, November 1992.

Crashes on controlled access roads are examined through recent studies. Findings include that increased restrictions to access increase flow of traffic and reduce unexpected events. Crash rates fall as restrictions increase. However, studies have shown that single action such as restriction to access or access entrance/exits are not as effective in isolation but rather in combination. Access control on non-freeways also has proven effective. Restricting the number of access points per mile reduces crash rates. Literature referenced through 1991.

Cirillo, Julie A., Stephen K. Dietz, and Richard L. Beatty. *Analysis and Modeling of Relationships Between Accidents and the Geometric and Traffic Characteristics of the Interstate System.* Washington, DC: U.S. Department of Transportation, 1969.

"City Traffic Engineers Generally Satisfied with Available Accident Data." *Urban Transportation Monitor* 4, no. 9 (11 May 1990) 1, 10–11.

Of 35 agencies responding to survey, 97% believed that crash reports were good for their purposes. Only 3% found crash data poor. However, approximately 25% commented that the data were not timely enough. Engineers surveyed used the crash data for HHLs, signal and stop warrants, legal defense, countermeasure evaluation, and responding to parking concerns. However, with exception of HHL and warrants, data were not reliable or of sufficient quality for most tasks.

Council, Forrest M., and Elizabeth G. Hamilton. *Guidebook for the Maine State Data Files.* Chapel Hill, NC: Highway Safety Information System, Highway Safety Research Center, March 1991.

Manual provides a guide to the fields submitted by the state. It also addresses issues regarding quality of data submitted from both the vehicle crash data and the roadway inventory files.

Council, Forrest M., and Elizabeth G. Hamilton. *Guidebook for the Minnesota State Data Files.* Chapel Hill, NC: Highway Safety Information System, Highway Safety Research Center, March 1991.

Manual provides a guide to the fields submitted by the state. It also addresses issues regarding quality of data submitted from both the vehicle crash data and the roadway inventory files.

Council, Forrest M., and Elizabeth G. Hamilton. *Guidebook for the Michigan State Data Files.* Chapel Hill, NC: Highway Safety Information System, Highway Safety Research Center, March 1991.

Manual provides a guide to the fields submitted by the state. It also addresses issues regarding quality of data sub-

mitted from both the vehicle crash data and the roadway inventory files.

Council, Forrest M., and Elizabeth G. Hamilton. *Guidebook for the Utah State Data Files.* Chapel Hill, NC: Highway Safety Information System, Highway Safety Research Center, March 1991.

Manual provides a guide to the fields submitted by the state. It also addresses issues regarding quality of data submitted from both the vehicle crash data and the roadway inventory files.

Council, Forrest M., and Elizabeth G. Hamilton. *Guidebook for the Illinois State Data Files.* Chapel Hill, NC: Highway Safety Information System, Highway Safety Research Center, March 1991.

Manual provides a guide to the fields submitted by the state. It also addresses issues regarding quality of data submitted from both the vehicle crash data and the roadway inventory files.

Council, Forrest M., and Jeffrey F. Paniati. "The Highway Safety Information System (HSIS)." *Public Roads* 54, no. 3 (December 1990) 234–240.

Federal Highway Authority (FHWA) set up HSIS to collect data from the selected states. File uses elements from both vehicle crash data and roadway-inventory data. Specifically includes roadway design, volume, and crash elements. Have included a high degree of quality control to help ensure data are valid for research purposes. HSIS does not represent statistical sample. File does not combine data from different states because of lack of similarity in definitions and coding of various elements. Performs study using database from one state and then examines others to see if findings are supported. Data are stored in SAS format. Requests for reports pass through FHWA; generally data not directly available to researchers.

Courage, Kenneth G. "The Small Computer Accident Records System (SCARS)." *Microcomputer applications in transportation III: proceedings of the International Conference on Microcomputers in Transportation.* 514–524. New York: American Society of Civil Engineers, 1990.

Craus, Joseph, Moshe Livneh, and Ilan Ishai. "Effect of Pavement and Shoulder Condition on Highway Accidents." *Transportation Research Record 1318.* 51–57. Washington, DC: Transportation Research Board, 1991.

The effect of pavement surface condition on traffic accidents was investigated as part of an Israeli Public Works Department survey of the feasibility of investing in the maintenance of the interurban road network in Israel. Analysis of this problem for the whole network attempted to correlate the state of the pavement surface with conditions of safety. The results of the investigation did not indicate any unilateral correlation between these two parameters. In contrast, similar tests that concentrated on specific road sections indicated that an increase in pavement surface grading might improve or worsen traffic safety, depending on the geometric and traffic characteristics of the section under investigation. Additional tests conducted in the context of this survey concerned the state of the pavement shoulders and the slipperiness of the pavement. According to Israeli data, it is possible to decrease the total number of accidents (non-intersection accidents) on the interurban road network by approximately 7.5 percent if the skid coefficient of the pavement surface, as measured by the Mu-Meter, is greater than 37. Similarly, it is possible to diminish the number of accidents by about 8 percent if the shoulder's surface is in good condition and the width of the shoulders is no less than 2 m. The findings of this investigation indicate that black sports or black section analyses are required rather than an analysis of the whole network to determine the pavement and shoulder condition on highway accidents. An application of the black sports or black sections concept facilitates the achievement of an optimal level of economic feasibility. Thus, for example, antiskid treatments provided at those sections where there is a high rate of accident of this type, or treatment of pavement shoulders and their widening at those sections where there is a high rate of accidents caused by a state of disrepair, can lead to high benefit-cost values.

"Critical Automated Data Reporting Elements for Highway Safety Analysis." *Federal Register, Docket No. 90-07* 57, no. 8 (13 January 1992) 1302.

Presents the elements which are considered as critical and should be included on all crash reporting forms. Includes the findings of a report by the National Safety Council's CADRE Task Force Report presented May 31, 1991.

Crowley, James D., and Owen S. Denman. "Site-Specific Issues: Application or Misapplication of Highway Safety Appurtenances." *Transportation Research Record 1367.* 84–91. Washington, DC: Transportation Research Board, 1992.

The misapplication of safety appurtenances sometimes occurs because designers do not have a thorough understanding of appurtenance characteristics or how they should be applied to hazards. The primary reasons include the following. First, highway appurtenance application and use guidelines are limited. Second, the background knowledge and experience of designers is declining as a result of turnover and retirement. Third, appurtenance characteristics are not always published in a consistent and useful form. Fourth, the number of alternative appurtenances has increased. Fifth, the existing appurtenance approval procedures group devices into broad categories that do not adequately describe the intended use or limitations of any specific system. Providing better information and training to designers can result in better application of safety appurtenances. Designers should understand critical site considerations and system characteristics and have access to guidelines for selecting the appropriate system characteristics to address each specific site.

Researchers, industry associations, manufacturers, FHWA, AASHTO, and others should work together to improve the information provided to designers. A document could be published in which the testing, critical site considerations, system characterization, and application information are combined. Designers need this information to make proper applications of safety appurtenances. This paper is focused on why safety appurtenances are misapplied, and steps to improve the overall situation are recommended. Detailed descriptions of key site considerations, system characteristics, and system testing and evaluation requirements are discussed.

Culkin, Donald S., Adam C. Thackston, and Willard A. Stanback. *Assessment of Tort Liability Risk Management in the Virginia Department of Transportation.* VTRC89-R8. Charlottesville, VA: Virginia Transportation Research Council, September 1988.

The Virginia Department of Transportation (VDOT) faces a growing tort liability problem. Under the Virginia Tort Claims Act, VDOT is liable for up to $75,000 for negligent or wrongful acts or omissions committed by its employees within the scope of their employment. VDOT must also pay judgments rendered against its employees as individuals for acts of negligence committed within the scope of their employment. In many cases, sovereign immunity will protect VDOT employees from tort claims. However, courts are increasingly willing to find state employees liable for negligent acts or omissions. To control future liability exposure, VDOT must develop a program to reduce the risk of tort liability. A comprehensive risk management system would attack the problem at three points. First, by making the roadways safer, the number of claims would be held to a minimum. Second, by improving VDOT's ability to defend tort claims, the number of claims paid and amounts awarded would be held to a minimum. Finally, by quickly settling claims that VDOT will inevitably lose and by setting aside money to pay such claims, a risk management program would assure that VDOT is prepared for unavoidable tort liability. This report documents the findings of the initial phase of VDOT's effort to develop a comprehensive risk management system. The purpose of this phase was to assess VDOT's exposure to tort liability and to describe existing efforts for controlling risk. In subsequent phases, the findings discussed herein will be used to design and implement improvements in VDOT's existing risk management efforts. VDOT's risk-causing activities include the design, construction, and maintenance of roadways. Claims alleging negligent maintenance are the most frequently filed, but only 13 percent of these claims are paid. The low success rate of these claimants indicates that VDOT is effectively responding to roadway defects even though there are currently no formalized procedures for ensuring an effective response. VDOT obtains information about roadway defects from many sources. However, there are no uniform policies for collecting such information or for agencywide distribution of the important information produced by these various sources. VDOT attempts to transfer some risks to contractors and consultants through indemnity and insurance agreements. Risks that cannot be prevented or transferred are assumed through self-insurance.

Curren, J. E. "Use of Shoulders and Narrow Lanes to Increase Freeway Capacity." *NCHRP Report 369*, Transportation Research Board, National Research Council, Washington, DC, 1995.

Danielsson, Stig. "Estimating the Effects of Countermeasures on Different Types of Accidents in the Presence of Regression Effects." *Accident Analysis and Prevention* 20, no. 4 (August 1988) 289–298.

In an earlier paper (Danielsson, 1986), the problem of estimating the safety effect of a countermeasure on the expected number of accidents at road junctions when high-accident sites are selected for the study was studied. Often, however, the countermeasure leads to varying effectiveness on different types of accidents. This paper is a generalization in that the effects of countermeasures for each type of accident are estimated. A major result, for which empirical support is provided, is that the expected regression effect is the same for all types of accidents.

Datta, Tapan K. "Head-On, Left-Turn Accidents at Intersections with Newly Installed Traffic Signals." *Transportation Research Record 1318*. 58–63. Washington, DC: Transportation Research Board, 1991.

Installations of traffic signals at intersections are often associated with changes in the accident characteristics at those sites. Past studies have indicated a reduction in the severity of accidents, but in some instances accident frequencies have increased. Traffic signals also influence changes in the distribution of accident types. Head-on, left-turn accidents at signalized intersections are of great importance to traffic engineers. A study of newly installed traffic signals was performed in Michigan to evaluate the changes in the distribution of accident types, including head-on, left-turn accidents. This study involved statistical testing of before and after accident rates at groups of similar intersections. The results of this study indicated an increase in head-on, left-turn accidents at the group of signalized intersections with and without separate left-turn lanes. However, the rate of increase in such accidents at locations without a separate left-turn lane was not significant at the 95 percent confidence level. The group locations in which a separate left-turn lane was installed along with the traffic signals also did not indicate a statistically significant change in the head-on, left-turn accident rate.

Datta, Tapan K. "Roadway Defect Surveillance - A Personal Computer-Based System." *ITE Journal* 65, no. 8 (August 1995) 26–33.

The author identifies a need for a local-agency complaint-documentation database and defect-surveillance system to

help overcome the lack of personnel available to focus on identifying highway safety improvement needs. The need for risk management is a major driving force behind such a system. Typical data needs and data processing are described. An automated system has been developed by the author to accomplish a basic system for handling and documenting citizen complaints and employees' reports of problems identified for the road system.

Datta, Tapan K., Thomas R. Krycinski, and William C. Taylor. "Highway Risk Management System - A Michigan Program." *ITE Journal* 61, no. 10 (October 1991) 15–20.

Risk management in Michigan modeled after work done in private industry to reduce costs arising from lawsuits. Needed in current economic and legal environment. Added benefit is reducing risks to drivers in general. All of agency must contribute. Cannot be reactive; must identify and take corrective action prior to an event. Also, once an event has occurred, must take positive steps to identify and correct, where possible, elements which led to problem. The benefits to the department include improved crash analyses, development of countermeasures, and knowledge of defects in roadway design and construction.

Davis, Gary A., and Konstantinos Koutsoukos. "Statistical method for identifying locations of high crash risk to older drivers." *Transportation Research Record 1375*. 61–67. Washington, DC: Transportation Research Board, 1992.

Deighton, Richard A., and Gary R. Ruck. *Microcomputer Applications in Transportation III*. 684–694. New York: American Society of Civil Engineers, June 1989.

For road and highway management it is becoming increasingly important to integrate data such as: traffic, accidents, geometrics, pavement condition, maintenance, and construction history. This integration process may become a major task since it is complicated by the tendency for each data gathering department within an agency to assemble data which only meets their specific needs without consideration of the needs of other departments. When combining two highway databases the first problem is frequently that each database divided the road network into a different set of sections. The problem is sometimes compounded by each department using a different location reference system in each database. At first this problem seems capable of ready solution by simply selecting a standard location reference system. Experience has shown, however, that a location reference system which is optimal today may not be the most suitable tomorrow when some new requirements are placed on the database. Thus, a flexible generic location reference system could offer great benefits. The flexible generic system would need to be able to receive and output data according to any number of different systems. Richard Deighton Associates Limited have been faced with such problems on many occasions while custom developing seven of these road database systems over the past six years. Thus, they have obtained private research funding and have developed a flexible generic location reference system, which is described in this paper. This system is an important component of 'dROAD' - the road database system which has developed and is being marketed by Richard Deighton Associates Limited. Using the Deighton flexible generic roadway location reference system and a proper set of computer procedures, it becomes practical for a single integrated roadway database to exist in an agency. This 'corporate' database receives data from many departments, each in their own form, and gives back output in their own form, while at the same time making their data available for other departments or other uses in the form required by those users. This is a road location reference system and a set of procedures, which is generic and fully flexible, can be readily implemented by any highway or railway agency in the world.

Designing Safer Roads. Special Report 214. Washington, DC: Transportation Research Board, 1987.

A compendium of papers devoted to aspects of roadway design which can enhance the safer movement of vehicles.

"Differential GPS and California's Disasters." *Government Technology* 8, no. 10 (October 19958) 22–24.

Dunlap, R., P. S. Fancher, R. E. Scott, C. MacAdam, and L. Segel. "Influence of Combined Highway Grade and Horizontal Alignment on Skidding." *NCHRP Report 184*. Washington, DC: Transportation Research Board, 1978.

Eck, Ronald W., and Donald L. Williams. "Traffic Engineering Evaluation of State Driver Licensing Manuals." *Transportation Research Record 1376*. 31–34 Washington, DC: Transportation Research Board, 1992.

The contents of state driver licensing manuals were reviewed from a traffic engineering standpoint. On the basis of a review of published materials and discussions with educators and engineers, a list of topics was identified against which each manual was evaluated. By identifying the extent to which the manuals covered current traffic operational features, specific conclusions were reached and recommendations were made. The results indicated that driver licensing manuals do not adequately cover traffic operational topics. Each manual had strong points, but none covered every area examined in the research. Many manuals depicted important traffic control devices, but few actually gave satisfactory explanations of a device's meaning or location. A model manual that contains suggested topics is recommended as a first step in improving the manuals from a traffic engineering viewpoint. Better interaction and cooperation between the motor vehicle administrators and public relations personnel who write the manuals and engineers who implement traffic control features will ensure that the manuals reflect current highway practice.

Experimental Plans for Accident Studies of Highway Design Elements. DTFH61-92-C-00031. Washington, DC: Federal Highway Administration (in progress).

Elvik, Rune. "The Safety Value of Guardrails and Crash Cushions: A Meta-Analysis of Evidence from Evaluation Studies." *Accident Analysis and Prediction* 27, no. 4 (1995) 523–549.

Evidence from 32 studies that have evaluated the safety effects of median barriers, guardrails along the edge of the road, and crash cushions (impact attenuators) is summarized by means of a meta-analysis. A total of 232 estimates of safety effects are included in the meta-analysis. The presence of publication bias is tested by means of the funnel graph method. For most subsets of the data, no evidence of publication bias is found. Weighted mean estimates of safety effects are computed by means of the log odds method. Median barriers are found to increase both accident rate and accident severity. Guardrails and crash cushions are found to reduce both accident rate and accident severity. The effects of guardrails and crash cushions have been less extensively studied than the effects on accident severity. Current estimates of the effects on accident rate are highly uncertain because of methodological shortcomings of available studies. The effects of guardrails on accident severity are found to be quite robust with respect to study design and number of confounding variables controlled in each study. In general, random variation in the number of accidents is the most important source of variation in study results.

Emoto, Takeshi C., and Adolf D. May. *Operational Evaluation of Passing Lanes in Level Terrain*. Berkeley, CA: Institute of Transportation Studies, February 1988.

Erickson, Raymond C. Jr. *A Field Test of Grade Severity Rating System*. DTR R85-6. Denver, CO: Colorado State Department of Highways, April 1985.

Truck brake temperatures on grades is a major problem causing runaway trucks. Control of temperature through speed control would likely be the single best preventive measure. However, no one method was found to obtain better control over truck speeds.

Evans, Andrew W. "Evaluating Public Transport and Road Safety Measures." *Accident Analysis and Prevention* 26, no. 4 (1994) 411–428.

This paper discusses three approaches to the evaluation of transport safety measures—labeled cost-benefit analysis, industrial risk assessment, and the elimination of all avoidable accidents—and the institutional settings in which each is dominant. This paper considers the application of these approaches primarily to road and rail safety measures in Great Britain. It is suggested that the elimination of all avoidable accidents should be rejected because of its large and open-ended resource requirement, but it is acknowledged that this is difficult because it implies the acceptance of avoidable accidents on public transport systems. The paper suggests a framework drawing on the other two approaches, in which cost-benefit analysis is combined with a limit on the tolerable risks to individuals. The author discusses cost-benefit analysis and how it has been applied specifically to road crashes. In Great Britain it is used to test return on investment. Industrial risk assessment is used primarily to evaluate changes to work place safety. Societal risk is used as part of the assessment. Elimination of all avoidable crashes primarily affects the study of major events such as airplane crashes. Use of this last measure for roadway crashes is not feasible, even though it appeals to the public.

Fairlie, R. B., and M. A. P. Taylor. "Evaluating the Safety Benefits of Local Area Traffic Management." *Proceedings, 15th Annual Conference*. 141–166. Australia: Australian Road Research Board, August 1990.

Traffic safety has traditionally been measured in terms of accident frequencies and severity and/or a measure of accident exposure. Absolute frequencies (i.e., accident numbers) alone provide insufficient information to adequately assess the safety of a particular location or to evaluate the performance of an accident countermeasure. Details of the operation of a countermeasure and the accident process are required to provide better understanding of accident causation and to develop more effective countermeasures. 'Improved safety' is a primary goal of much Local Area Traffic Management (LATM) work, but the evaluation of accident countermeasures in local areas, based on accident statistics alone, is difficult as these accidents tend to be spread areawide in low quantities. Although the concentration of accidents in local areas is low, a significant safety problem exists—up to one-third of all urban casualty accidents occur on local streets. Pedestrians and cyclists, especially the old and the young, are particularly vulnerable. Traditional evaluation techniques have limitations when applied to local area studies, especially when statistically conclusive results are sought. This paper describes the rigorous evaluation of the safety benefits resulting from two 'case studies' of LATM schemes in metropolitan Sydney, in the municipalities of Canterbury and Willoughby. In each of these cases, before and after periods of at least three years' duration each were available. This was set as a minimum criterion for analysis, and the two LATM schemes evaluated were the only ones available that met this criterion. Difficulties in providing reductions in traffic crashes on local streets relate to neighborhood 'acceptance' of devices. A number of different approaches have been attempted.

Fambro, Daniel B., Kay Fitzpatrick, and Roger J. Koppa. *Determination of Stopping Sight Distances*. Washington, DC: National Academy Press, 1997.

Fambro, D. B. *et al. Stopping Sight Distance Consideration at Crest Vertical Curves on Rural Two-Highways in Texas*. TX-90/1125-1F. Austin, TX: Texas Transportation Institute, March 1989. NTIS, Springfield, VA.

Rehabilitating or upgrading existing two-lane roadways sometimes involves design decisions concerning improved vertical alignment and roadway cross section. These decisions are especially critical whenever the existing alignment does not meet current standards. In order to make these decisions in a cost-effective manner, the safety and operational effects of alternative crest vertical curve designs must be known. This study attempted to quantify those effects. In summary, the study concluded that the relationship between available sight distance on crest vertical curves and accidents is difficult to quantify; that the AASHTO stopping sight distance model is not a good indicator of accidents on two-lane roads; and that when there are intersections within the limited sight distance portions of crest vertical curves, there is a marked increase in accident rates. There was also no definitive relationship between available sight distance and operating speed on crest vertical curves.

Fawaz, B., and L. Mountain. "'Accident Migration' Following the Implementation of Highway Engineering Schemes." *Mathematics in Transport Planning and Control (Proceedings).* 421–432. Oxford, England: Clarendon Press, 1992.

The observed 'migration' of traffic accidents from treated sites to their neighbors has been the subject of considerable controversy in recent years. Some authors have argued that the observed migration represents a real change in the underlying mean accident frequencies at the sites involved, while others have argued that it is merely a statistical illusion arising, like regression-to-mean, due to a bias by selection. In this paper a detailed data set is examined with a view to separating any changes in observed accidents which reflect real changes in the underlying mean accident frequencies from changes which are due to change alone. It is shown that, although regression-to-mean effects can give an illusion of accident migration, regression-to-mean does not explain the observed accident migration at treated sites. Note also Loveday and Jarrett (elsewhere referenced) on this same subject.

Fife, D., and R. Cadigan. "Regional Variation in Motor Vehicle Accident Reporting: Findings from Massachusetts." *Accident Analysis and Prevention* 21 (April 1989) 193–196.

The authors examined injury-producing crashes in 45 of the largest municipalities in Massachusetts. Ability to match police reports showing injury with injury treatments range from 28 percent to greater than 85 percent demonstrates a problem that crash rates may be 'consistently under-reported' rather than a 'low' rate as the data might suggest. Before using crash reports, authors recommend adjusting numbers by differences in reporting found from city to city. An optional approach is to use fatal crashes adjusted to a total value. This latter approach, however, presumes that fatal crashes occur in the same proportion as other crashes through a region; this clearly is not the case.

Fink, Kenneth L., and Raymond A. Krammes. "Tangent Length and Sight Distance Effects of Accident Rates at Horizontal Curves on Rural Two-Lane Highways." *Transportation Research Record 1500.* 162–168. Washington, DC: Transportation Research Board, 1995.

Most models for evaluating operating-consistency on two-lane rural highways estimate operating-speed profiles based on tangent length and degree of horizontal curvature. Some models also consider the effect of sight distance to horizontal curves. To add insight on the effects of these variables on safety and operations at horizontal curves, a base relationship between accident rates at horizontal curves and degree of curvature was established, and the effects of approach tangent length and approach sight distance on this relationship are examined. The results confirm that degree of curvature is a good predictor of accident rates on horizontal curves. Although the effects of approach tangent length and sight distance were not as clear, the results suggest that the adverse safety effects of long approach tangent length and short approach with distance become more pronounced on sharp curves.

Fitzpatrick, Kay. "Gaps Accepted at Stop-Intersections." *Transportation Research Record 1303.* 103–112. Washington, DC: Transportation Research Board, 1991.

Gap-acceptance data are used to determine intersection sight distance, capacity, queue length, and delay at unsignalized intersections. They have also been used to determine the need for a traffic signal, the capacity of a left-turn lane, and warrants for left turn signal phasing and storage lanes. A field study was performed to determine the gap-acceptance values of truck and passenger car drivers at six intersections. Each intersection was formed by two 2-lane roads; the minor road was controlled by a stop sign. The data obtained in the field were evaluated by three methods: Greenshield, Raff, and logit. The findings from the field studies were summarized into generalized values. Passenger car drivers had a 50 percent probability of accepting a gap of 6.5 sec for both left and right turns and an 85 percent probability of accepting a gap of 8.25 sec at a moderate- to high-volume intersection. A 10.5-sec gap represented the 85 percent probability of accepting a gap at an intersection where accepted gaps were influenced by low volume and the intersection's geometry. Truck drivers' 50 percent probability of accepting a gap was 8.5 sec. At a high-volume location, 85 percent of the truck drivers accepted a 10 sec gap; at a low-volume location, 15.0 sec was the accepted gap value.

Fitzpatrick, Kay, and Kevin Balke. "Evaluation of Flush Medians and Two-Way, Left-Turn Lanes on Four-Lane Rural Highways." *Transportation Research Record 1500.* 146–152. Washington, DC: Transportation Research Board, 1995.

Three types of medians are typically used on four-lane rural highways in Texas: raised (or depressed) medians; two-way, left-turn lanes (TWLTLs); and flush medians. With flush medians, the area between the travel lanes is

paved and can easily be traversed by a vehicle. This type of median is typically used in areas that transition from rural to suburban. Research was conducted to examine the differences in the operations and safety of four-lane rural highways with TWLTLs and four-lane rural highways with flush medians. A review of accident rates found that there were no statistical differences in accident rates of highways with TWLTLs and highways with flush medians when driveway densities were low. Field studies also showed that there was no difference in the way these two median treatments operate in rural areas. Therefore, it was concluded that drivers use flush medians and TWLTLs similarly. Texas state law states, however, that it is illegal for motorists to use flush medians as a storage and acceleration/deceleration area for turning left into and out of adjacent properties. The results of the research suggest that drivers ignore the meaning of the solid yellow lines used to mark flush medians. Therefore, in order to promote uniformity and consistency, it is recommended that flush medians be used only on highways where the frequency and spacing of driveways permit individual median openings at each driveway. In cases where this is not possible, it is recommended that TWLTLs be used on four-lane rural highways.

Fitzpatrick, Ray, Dan Middleton, and Debbie Jasek. "Countermeasures for Truck Accidents on Urban Freeways: A Review of Experiences." *Transportation Research Record 1376*. 27–30. Washington, DC: Transportation Research Board, 1992.

Because of the rise in truck volume, the interaction of these large vehicles with other traffic, and the publicity given to major truck accidents, public awareness of the consequences of truck accidents and incidents is heightened. A literature review, telephone interviews, and visits to selected sites provided information on several truck accident countermeasures implemented on high-volume urban freeways. An FHWA survey found that 15 states have restricted trucks to certain lanes to improve highway operations. New Jersey Turnpike and I-5 north of Los Angeles have sections on which trucks are restricted to a separated facility. Ramp treatments include reconstruction to remove outside curbs, installation of tall barriers, evaluation of the appropriateness of posted ramp speeds, and active and passive warning signs. Truck diversions or bans exist in Minneapolis-St. Paul, south of Cincinnati, San Diego, Los Angeles, and Atlanta. Allowing trucks to park in a park-and-ride lot during nighttime hours and increasing enforcement to restrict the length of stay in inappropriate locations (i.e., shoulders or along entrance and exit ramps) are measures used to reduce shoulder parking. Maryland, Virginia, and California have urban truck inspection stations, and Chicago, Tampa, and Seattle have elements of their incident management program directed toward trucks.

French, A., and D. Solomon. "Traffic Data Collection and Analysis: Methods and Procedures." *NCHRP Synthesis of Highway Practice No. 130*. Washington, DC: Transportation Research Board, 1986.

This report mainly concerns exposure information, discussing telemetry, air tubes, AVC (automatic vehicle classification), WIM (weigh-in-motion) capabilities, AVI (automatic vehicle identification), manual classification counting, development of automated procedures using infrared, video and pattern recognition technology, HPMS, and continuing efforts to develop an integrated efficient transportation data system.

Garber, Nicholas J., and Woo Tzong-shiou Hugh. "Effectiveness of Traffic Control Devices in Reducing Accident Rates at Urban Work Zones." *Traffic Quarterly* 452, no. 2 (April 199145) 259–270.

Need to identify the most effective combination of traffic control devices to reduce crashes in work zones. In the study, the researchers used both frequency of crashes and crash rates from selected sites in Virginia cities and examined changes in frequency and rates based on combinations of traffic control devices used. Most combinations of devices worked better than had no devices been in place. This finding occurred on both two-lane and multilane roads. Principal finding: Crash rates will increase in work zones, regardless of devices in place. Only combinations using barricades showed lack of improvement.

Gattis, J. L., and John Duncan. "Geometric Design for Adequate Operational Preview of Road Ahead." *Transportation Research Record 1500*. 139–145. Washington, DC: Transportation Research Board, 1995.

This paper discusses minimum geometric conditions that must exist to provide an ample amount of 'preview sight distance' (PVSD) for comfortable and safe traffic operations. The PVSD concept is based on the assumption that the driver views or 'previews' the roadway surface ahead, as well as other cues that may lie ahead, to obtain the information needed for vehicular control and guidance. The driver needs a minimum PVSD in order to perceive and respond to upcoming alignment cues; the roadway geometry affects how much PVSD is actually available for the driver. A roadway designed with geometric features adequate for the design speed would in many cases provide ample PVSD, but a roadway with constrained design features may have inadequate PVSD. The paper includes a derivation of equations to calculate the available preview sight distance on a crest vertical curve and discusses two applications of the PVSD concept to sharp horizontal curves. When a geometric analysis finds that inadequate PVSD exists, upgraded signing or pavement marking to provide the driver with extra positive guidance may be considered as a means of compensating for the inadequate PVSD.

Gattis, J. L., John P. Varghese, and Larry E. Toothaker. "Analysis of Guardrail-End Accidents in Oklahoma." *Transportation Research Record 1419*. 52–62. Washington, DC: Transportation Research Board, 1993.

Researchers at the University of Oklahoma documented attributes associated with accidents in which vehicles struck guardrail ends. The database included accidents at a variety of guardrail-end types, but most ends were either exposed or turned down. The severity of exposed and of turned-down guardrail-end accidents in relation to lateral location of the guardrail and to vehicle rolling and vaulting was investigated. Individual accident reports were read carefully to obtain information for the analyses. The results showed that on divided roads, vehicles struck median guardrail ends about as often as right-side ends. On undivided roadways, right-side ends were struck about 60 percent of the time. Approximately a sixth of the accidents were fatal of incapacitating-injury accidents. In most of them, the vehicle did not vault or roll. The research did indicate that turned-down guardrail ends were associated with more vehicle rolling and vaulting than the exposed ends. Roughly a third of all guardrail end accidents involved an inattentive driver striking a guardrail end. Most guardrail-end accidents on the state system occurred on a small portion of the system, namely the higher-volume roadways. The researchers suggested that accident reporting methods be enhanced, and that rumble strips be tested as a means to reduce guardrail end strike accidents. If newer, more expensive end treatments were installed, concentrating efforts on a small portion of the system could address a majority of the accidents sited.

Geographic Information Systems - Transportation, ISTEA Management Systems Server-Net Prototype Pooled Fund Study, Phase A - System Architecture. unpublished, 17 June 1994.

This is an interim report of a Task Force of state personnel which was commissioned to create a comprehensive information systems architecture for coordinating and integrating transportation planning activities at all levels of government. A framework and system architecture is presented.

Gitelman, Victoria, and A. S. Hakkert. "Consideration of Safety Problems at Rail-Road Crossings Ranking for Grade Separation." *The Third International Conference on Safety and the Environment in the 21st Century.* 319–328. The Technion, Israel Institute of Technology, 7 November 1994.

A rail-highway crossing hazard ranking method is applied to cases in Israel. Data requirements included details regarding the roadway geometry at the crossing.

Gittings, Gary L. "An Analysis of the Characteristics of Highway Tort Liability: A State Perspective." Ph.D. diss., Pennsylvania State University, August 1987.
[see Gittings, February 1991].

Gittings, Gary L. "Highway Elements Associated with Tort Liability Actions." *Journal of Transportation Engineering* 117, no. 1 (February 1991) 103–123.

With the loss of sovereign immunity, risk management has become an important discipline for many state highway and transportation departments. One step in an effective risk management process is the evaluation of past tort claims and lawsuits to identify the fundamental characteristics of tort actions necessary for effective risk management decision making. This article reports the results of one such evaluation that identified the types of highway elements alleged to have contributed to highway incidents producing tort actions, develops a profile of high-risk elements in terms of the number of actions and the proportion of actions involving severe injuries or fatalities, and provides recommendations, supplemented with examples, on how this information should be used for safety-enhancement decision making in such diverse activities as routine maintenance and safety programming. Study of tort liability in Pennsylvania as it refers to roadway elements, proposes methods by which management can undertake risk assessment and control actions. Findings show that the most frequent source of liability arose from traffic control devices (generally missing or obscure), pavements (pot holes), and nonfixed objects (loose gravel, implements on highway, other obstacles on highway). Clear demarcation exists between those elements which resulted in many actions and those which resulted in few (e.g., missing signs versus poor design). However, when examining actions by severity of the injury (and generally size of the claim), percentage contribution varies. Most torts are for minor actions and are related to road defects. The serious actions relate to traffic control devices and design deficiencies. Recommends engineers use a matrix of tort frequency versus severity of injury in event and classify contributing roadway elements to each cell of the matrix. Transportation department needs to be pro-active, particularly where corrections can be made expeditiously and at a low cost. For more costly correction, need to consider the potential for tort and award versus the cost of making the changes which may or may not have held in court. [Original source: Gittings dissertation, Pennsylvania State University, August 1987].

Glennon, J. C. "Effect of Alignment on Safety." *State of the Art Report 6: Relationship Between Safety and Key Highway Features, A Synthesis of Prior Research.* 48–63 Washington, DC: Transportation Research Board, 1987.

Glennon, John C., et al. *Guidelines for the Control of Direct Access to Arterial Highways.* Kansas City, MO: Midwest Research, 1975.

Goldstine, Rachel. "Influence of Road Width on Accident Rates by Traffic Volume." *Transportation Research Record 1318.* 64–69. Washington, DC: Transportation Research Board, 1991.

A study was conducted to assess the effect of shoulder and road widening on accident rates. Twenty-five projects covering 152 mi of road were selected for analysis. Sampled roads

had been widened to one of four widths: 32, 36, 40, or 44 ft. Accident rates were compared before and after the construction period. Reductions of 38 to 53 percent were observed in accident rates, although the amount of reduction varied with traffic volume and the roadway width after construction. Accident rate reduction for the sampled projects was statistically significant at the 95 percent confidence level for before and after comparisons on most of the roads. Further research of the effects of resurfacing, restoration, and rehabilitation projects on accident rates in New Mexico is recommended.

Golias, J. C. "Establishing Relationships between Accidents and Flows at Urban Priority Road Junctions." *Accident Analysis and Prevention* 24, no. 6 (December 1992) 689–694.

Explores effects of traffic stream flows on potential for accidents at urban, priority-controlled (unsignalized), four-leg intersections. Studied 43 intersections in Texas and controlled sampling so that author believes that the only variable was traffic flow. Examined crash data for 5-year period. Introduced new expressions for the original prediction model sum/sum Q(I) Q(j) where Q is the traffic flow on each of merging traffic streams. Found that sum of Q(I) times sum of Q(j) to the 0.5 was a better predictor of crashes with an r = 0.89.

Golob, Thomas *et al.* "An Ordinal Multivariate Analysis of Accident Counts as Functions of Traffic Approach Volumes at Intersections." *Accident Analysis and Prevention* 20, no. 5 (October 1988) 335–356.

This research is concerned with the statistical analysis of accident counts at nonsignalized intersections. The objective is to develop a method for determining general (nonlinear) relationships between approach volumes and accident counts. The method must accommodate the testing of whether intersections of differing physical designs have higher or lower rates of accidents than predicted by traffic levels. It is assumed that only aggregate data are available: (1) counts of total accidents by type (e.g., injury versus property damage) without details concerning the locational position(s) of the vehicle(s) involved; and (2) aggregate traffic intensity on each intersection entry without details concerning turning volumes. The method involves the application of nonlinear multivariate methods to variables treated as ordinal scales. A case study application involving four-leg and three-leg ('T') nonsignalized major arterial intersections in the Netherlands is described. The effect of bicycle traffic on accident rates is included in the case study analysis. The results indicate that there are three groups of each of the two types of intersections based on traffic flow patterns. For each group, a different functional form was found to relate accident rates and specific variables measuring traffic volumes. There were no significant differences among the physical design categories of the intersections in each group that were not accounted for by differences in traffic intensities.

"Government Solutions Center." *Government Technology* 8, no. 8 (August 1995) 46.

Ha, Tae-Jun, and Z. A. Nemeth. "Detailed Study of Accident Experience in Construction and Maintenance Zones." *Transportation Research Record 1500*. 38–45. Washington, DC: Transportation Research Board, 1995.

The objective of this study was to identify means by which improved traffic control can improve traffic safety at work zones. The accident database was derived from the coded information stored in the computerized data bank of the Ohio Department of Highway Safety. Coding errors and unreported accidents were recognized as limitations of the database. Statistical analysis of statewide aggregate data failed to identify cause and effect relationships between accident characteristics and traffic control. The study was expanded to include the review of individual accident reports at nine construction sites. This approach proved very effective. The accident reports, which always included a sketch and a description of the event, often indicated that specific traffic control procedures and standards needed to be improved. It has become clear to the researchers that certain types of accidents at a given work zone can suggest specific problems with traffic control plans and/or with implementation of the plans. Monitoring work zone accidents as they happen is, of course, the best way to recognize and eliminate problems. In fact, independent of this study, a Work Zone Task Force of the Ohio Department of Transportation (ODOT), which included engineers with intimate knowledge of work zone traffic control practices based on field experience, has already recommended improvements in traffic control standards and practices.

Hadi, Mohammed A., J. Aruldhas, L.F. Chow, and J. A. Wattleworth. "Estimating the Safety Effects of Cross-Section Design for Various Highway Types Using Negative Binomial Regression." *Transportation Research Record 1500*. 169–177. Washington, DC: Transportation Research Board, 1995.

Improvements to cross-section design are expected to produce reductions in crash rates. Previous studies on the subject have concentrated on two-way, two-lane highways with less attention given to other types of highways. In addition, several of those studies used conventional regression analyses which are not suitable to estimate a discrete nonnegative variable like crash frequency. This study uses negative binomial regression analyses to estimate the effect of cross-section design elements on total, fatality and injury crash rates for various types of rural and urban highways at different traffic levels. The results show that, depending on the highway type investigated, increasing lane width, median width, inside shoulder width, and/or outside shoulder width are effective in reducing crashes. The results also indicate that, on four-lane urban highways, a raised median is safer than a two-way left-turn lane median and that the use of open-graded friction course in lieu of dense-graded friction course does not have an adverse effect on crash rates.

Hajek, Jerry J., J. Billing, P. Hoang, and A. J. Ugge. "Use of Weigh-in-Motion Scale Data for Safety-Related Traffic Analysis." *Transportation Research Record 1467*. 38–43. Washington, DC: Transportation Research Board, 1994.

So far, more than 2000 traffic lanes on North American highways have been equipped with weigh-in-motion (WIM) scales. These WIM scales provide and will continue to provide a large amount of data for individual highway vehicles, such as axle spacing and weights, vehicle length, speed, and headway. Because of their unobtrusiveness and continuous operation, WIM scales provide unbiased, statistically reliable data. The use of WIM data for investigating safety-related highway traffic flow characteristics is examined. WIM technology and its capabilities to generate traffic-monitoring data useful for transportation planning and decisionmaking are described. Examples of data analysis that demonstrate the usefulness of WIM data for investigating safety-related traffic characteristics are provided. They include determination of truck exposure rates and evaluation of vehicle speed and headway distribution as a function of highway facility, vehicle type, daytime and nighttime conditions, and truck load. WIM data are useful in many areas of transportation planning, including safety-related traffic analysis and should be considered corporate data and managed accordingly.

Hall, J. W., and O. J. Pendleton. "Rural Accident Rate Variations with Traffic Volume." *Transportation Research Record 1281*. 62–70. Washington, DC: Transportation Research Board, 1990.

The relationship between hourly traffic volumes and hourly accident rates on rural highways in New Mexico was examined. The database consisted of traffic volumes at 44 permanent count stations and 3 years' accident experience on 10-mi roadway sections surrounding these stations. The highest accident rates occurred during hours with the lowest traffic volumes. Over the range of conditions examined, accident rates decreased with increasing traffic volumes and with increasing volume/capacity ratios. However, because of the moderate traffic volumes on these roadways, it was not possible to determine the effect on the accident rate as hourly traffic volumes approach capacity. In rural states such as New Mexico, further study of these issues should focus on higher-volume locations found in urban areas.

Hall, J. W., and Margarita Polanco de Hurtado. "Effect of Intersection Congestion on Accident Rates." *Transportation Research Record 1376*. 71–77. Washington, DC: Transportation Research Board, 1992.

Although there is general agreement that accident rates are highest during the periods of the day when traffic volumes are low, the change in accident rates as facilities become more congested is poorly understood. The peak-hour accident rates at several hundred signalized intersections in Albuquerque were examined in relation to their level of congestion, as reflected by volume/capacity (v/c) ratios. Accident rates exhibited a small but significant positive correlation with the amount entering traffic. On average, intersection accident rates are at a minimum in the range 0.6 less than or equal to v/c less than or equal to 0.8. However, equations developed for estimating accident rates as a function of v/c had such high standard errors that they could not be used for predictive purposes.

Hall, Jerome W. *Identification and Programming of Roadside Hazard Improvements*. Report Number FHWA-MD-R-77-4. University of Maryland, Transportation Studies Center: Federal Highway Administration, September 1978.

A hazard index is established for assessing the priority of roadside locations for correction/mitigation. Data needs for the Roadside Hazard Model include: distance from the road to the object, posted speed limit, or observed speeds of operation, object type and classification of severity of object, traffic volume, roadway curvature, and longitudinal grade.

Harkey, David L., and Rafael Ruiz. "HISAM—An Accident Database Manager." *Transportation Research Record 1238*. 37–44. Washington, DC: Transportation Research Board, 1989.

The Highway Safety Analysis and Monitoring software was developed under a FHWA research contract and is designed to aid local agencies with database development and accident analysis. The package of programs is designed to enter, retrieve, process, and analyze traffic accident report data, link description data, and node description data. The city of Charlotte, North Carolina, with a population of 350,000, was chosen as the test site for the developed software. The average 20,000 accidents per year provided an excellent database with which the software could be tested. By the end of the test phase the city was able to identify high-accident locations based on accident frequencies, accident rates, or EPDO indexes and rates. This paper describes both the data input and the report output of HISAM, as well as the city's experience with the software.

Harwood, Douglas W. "Relationships Between Operational and Safety Considerations in Geometric Design Improvements." *Transportation Research Record 1512*. 1–6. Washington, DC: Transportation Research Board, 1995.

Harwood, D. W., J. M. Mason, and J. L. Graham. *Conceptual Plan for an Interactive Highway Safety Design Model*. FHWA-RD-93-122. Washington, DC: Federal Highway Administration, February 1994.

This report presents a conceptual plan for an interactive highway safety design (IHSD) model under consideration for development by FHWA. This report combines elements of three separate plans for the IHSD model that were developed independently by different contractors. The report also includes elements of a plan for roadside safety models developed recently for FHWA. The IHSD model is intended as a

tool that could be used by a designer or design reviewer to assess the safety effects of specific highway geometric design decisions. The model would be interactive in that it would allow the designer to make changes in the geometric design and evaluate the safety effects of those changes as part of a single software package. A key element of the IHSD model would be an accident predictive model incorporating statistical relationships between geometric design elements and safety. Separate submodels would be provided for roadway sections, intersections, interchange ramps, speed-change lanes, and roadside areas.

Harwood, Douglas W., R. R. Blackburn, D. F. Kibler, and B. T. Kulakowski. "Estimation of Wet Pavement Exposure from Available Weather Records." *Transportation Research Record 1172*. 32–41. Washington, DC: Transportation Research Board, 1988.

The estimation of wet pavement exposure is critical to the effective management of programs aimed at reducing wet pavement accidents. Without a measure of wet pavement exposure, highway safety engineers cannot tell whether differences in wet pavement accident frequencies between sites or over time represent actual safety problems or merely result from site-to-site or year-to-year variations in rainfall frequency. Laboratory and field tests were conducted to investigate two key aspects of wet pavement exposure estimation: (a) the conditions under which pavement wetness reduces pavement surface friction and (b) the time required for pavements to dry after rainfall. The results of these tests were used to develop an improved method of estimating wet pavement exposure from available weather records. This method has been incorporated into a computer model, known as the WETTIME model, for application by highway agencies. The model estimates the number of hours with wet pavement conditions on monthly and annual bases.

Hauer, E. Department of Civil Engineering, University of Toronto. "Some Issues in the Management of Highway Safety." Paper presented at the National Workshop on Safety Management Systems-Methodology, Tucson, AZ, 14 July 1994.

The evaluation requirements of the SMS are discussed and critiques. Suggestions are made for approaches which deal with some of the issues raised. The discussion recognizes the importance of having available good quality crash and other safety data, but does not address this set of issues.

Hauer, E., and A. S. Hakkert. "Extent and Some Implications of Incomplete Accident Reporting." *Transportation Research Record 1185*. 1–10. Washington, DC: Transportation Research Board, 1988.

Cites 'partial ascertainment' as coming from 'the statistical literature.' Argues that a high percentage of reporting of all accidents 'is much to be desired.' Also that the actual threshold for reporting varies with driver age, location, severity, time of day. Authors argue that users should understand the degree of underascertainment and correct for it. Fourteen studies of underreporting of accidents (published from 1971 to 1985) are discussed. General conclusion is that fatalities are probably correct within 5 percent, but that probably 20 percent of injuries requiring hospitalization are not reported, and maybe 50 percent of nonhospital injuries. An analysis suggests that the variance of the estimate of safety (or the safety effect of some measure) is inversely proportional to the square of the average proportion of accidents reported. Many references, including a survey done by Morgenstein for NASS, which reported that 79 percent of injury accidents were reported and 54 percent of PDO. Another reference is Barancik and Fife, which found (for Ohio) that only 55 percent of all injuries were reported and only 28 percent of those under 16 years (based on a comparison of hospital data with that of the Dept. of Motor Vehicles). Hauer argues that it is very important to know the proportion of missing cases (which is a function of accident type, driver age, etc.) in order to make a realistic estimate of a problem. He suggests strongly that every jurisdiction should make such a determination.

Hauer, Ezra. "On Exposure and Accident Rate." *Traffic Engineering and Control* 36, no. 3 (March 1995) 134–138.

Use of exposure to equalize differences in intensity of use to help make meaningful comparisons, and to indicate overrepresentation so as to direct investigation into casual factors or help direct intervention. The denominator, or 'exposure measure,' varies depending on the type of accidents that are being assessed. Traffic often uses entering vehicles (for intersections) or vehicle miles (for segments), but airlines use per flight-hour, passenger mile, or departure. For roadway, rates may not be a true indicator of safety. For example, new roadway incorporating all safety engineering but with very low volume may have higher rate than heavily traveled older road because the exposure rate of new road is influenced significantly by volume of traffic. The difference in one crash can make a large change in rate. The second problem is that exposure measures may not be linear. For example, under linear constraint, crashes among trucks and cars are related to the flow of each as a proportion of each. Yet, changing either proportion does not have such a multiplicative effect. Author argues for use of expected values based on exposure 'before' and 'after.' Further, to use the measures adequately means that researchers must understand the intensity of use related to relevant crash frequency.

Hensing, David J. "The Roadway Environment: Progress in Making It Safer." *ITE Journal* 61, no. 7 (July 1991) 25–31.

Need to reexamine roadway using newer technology to ensure adequate safety. More research is needed in highway safety design and operation along with management of highway safety. However, must keep in mind the cost-benefit particularly with roadside design.

Highway Safety Information System. *Guidebook for the Maine State Data Files.* Chapel Hill, NC: Highway Safety Research Center, March 1991.

The Guidebooks provide a list of formats and information for the data managed for that state by the Highway Safety Information System. In the introductory discussion, each manual describes the results of error analysis of both the crash report and roadway inventory for the referenced state. Guidebooks are available for Maine, Minnesota, Illinois, Michigan, and Utah.

Higle, Julia L., and M. Hecht "A Comparison of Techniques for the Identification of Hazardous Locations." *Transportation Research Record 1238.* 10–19. Washington, DC: Transportation Research Board, 1989.

Techniques for the identification of hazardous locations, based on both classical and Bayesian statistical analyses, are evaluated and compared in terms of their ability to identify hazardous locations correctly. A simulation experiment, which is described in detail, is used. One classically based technique exhibits a tendency to error in the direction of false negatives. Another classically based technique yields relatively few false negative errors and produces results that are virtually indistinguishable from the results obtained from the Bayesian techniques. A variation of the Bayesian method proposed by Higle and Witkowski exhibits a tendency to perform well, producing low numbers of both false negative and false positive errors. Observed sensitivities of the various procedures are discussed.

Hopkin, Jean M. *et al. Police and Hospital Recording of Non-Fatal Road Accident Casualties: A Study in Greater Manchester.* Report 379. Crowthorne, Berkshire, England: Transport Research Laboratory, 1993.

A study of injuries recorded by police and hospitals was carried out in the course of research on the cost of road accident injuries. Casualty records for road accident patients treated at three hospitals in the Greater Manchester area over a six month period were collected and matched with police road accident records. The data were analyzed to identify the incidence of different types of injury and the distribution of injury severity and to estimate the extent to which police records under-report casualties or misclassify the severity of their injuries. The report summarizes the results, comparing the data recorded by the hospital with that recorded by the police for the national accident statistics. Reasons for the differences between the two sources of information are discussed, and the implications of the results for accident statistics are presented.

Hoque, M. D. M. "Accidents in Road Classes: A Review of Past Studies and Recent Advances." *Australian Road Research* 19, no. 1 (March 1989) 29040.

Disaggregation of data by road class shows some value for analytical purposes. For arterial and collector roads, the intersection represents the site of most crashes. For rural roads, most problems occur along the links. Clustering of crashes appears when disaggregation is done by road class and by type of crash. Clustering can be used to help address priorities for correction. The clusters are most likely to appear on the arterial roads and least likely on local streets. Further, clustering is more likely to indicate problems at intersections than along the links.

Hughes, Warren E. *et al. New and Emerging Technologies for Improving Accident Data Collection.* DTFH61-91-C-00043. Vienna, VA: Bellomo-McGee, Inc., March 1993. NTIS, Springfield, VA.

Report describes methods to improve the collection and reduction of traffic crash data through automated means. These methods are seen as a way to reduce the manual and timely steps required through use of various automated tools. Also, automation should lead to enhanced quality; it should provide data in computer-ready format, allowing quicker loading to databases and potentially making the data more available to users. Included in the recommendations are automated location through global positioning systems (GPS) with real-time differential systems (accuracy to 2M). Cellular phones can also provide accurate lactation through triangulation. This is more appropriate in urban areas where sufficient antennas exist. For field collection of data, laptop and other portable computers are to be used. For drivers and vehicles, use of both bar-coding and magnetic-stripe identification reduces errors in obtaining names and vehicle identification. Promising future technologies include voice recognition for data input, optical character recognition, 'smart' cards for personal identification, and driver and vehicle performance recording devices.

Hutchinson, T. P. "The Continuous Flow Intersection." *Traffic Engineering and Control* 36, no. 3 (March 1995) 156–157.

A triple conflict between traffic streams (for instance, an appreciable right-turning flow, as well as heavy straight-through flows) is often the key factor leading to limited capacity and high delay at a junction, either a three-legged T-junction or four-legged crossroads. It is possible to design a junction so that such a conflict is replaced by three lesser conflicts, each between only a pair of flows. This leads to higher capacity and less delay for a given amount of road-space.

Hyman, William A. "Pavement, Bridge, Safety, and Congestion Management System: A Need for Clear Federal Vision." *Traffic Quarterly* 47, no. 2 (April 1993) 151–166.

Study recommends that the information management systems associated with each of the classes (pavement, bridge, safety, and congestion) should be treated jointly as an Infrastructure Management System. In committing funds, there is a need to examine the network as a whole. Tendency is to treat pavement as getting 'x' dollars, bridges getting 'y' dollars, etc. Yet, this can result in an inequitable distribution of dollars to

improve safety in the network. Moreover, improvements in one element, such as pavement, may help improve safety or reduce congestion. Likewise, reductions in congestion may point to a need to improve pavement or bridges.

Ibrahim, K., and D. T. Silcock. "The Accuracy of Accident Data." *Traffic Engineering and Control* (September 1992) 492–497.

A mail survey was conducted of all 93 highway authorities in Great Britain. The analyses were based on a 95 percent response. The purpose of the survey included determining: the level of effort expended on checking accuracy of the crash reports and data entered, the types of inaccuracies most frequently occurring, and the degree of under-reporting of crashes. The results indicated that agencies expended considerable effort on maintaining data accuracy and often contact the police to resolve errors. It was also concluded that the most commonly occurring inaccuracies or difficulties encountered were: location coding, narratives, vehicle identifiers, injury data, road classification, and attendant circumstances. Estimates of under-reporting ranged from 14 percent for motor-vehicle crashes, to 29 percent for pedestrian crashes. The authors raise the issue that there is a practical limit to the level of accuracy achieved. Furthermore, they suggest an important trade-off in resource utilization between improved accuracy and reduced under-reporting.

Institute of Transportation Engineers. "Traffic Engineering Handbook, 4th Edition." Joseph L. Pline, Editor. Englewood Cliffs, NJ: Prentice Hall, 1991.

Handbook for use in designing all phases of the transportation system including volumes and traffic studies, capacity, headways, delays, intersection capacity, signal timing, intersection control. Also included are other transportation systems beside highways.

Ivey, Don L., M. E. Bronstad, and Linsay I. Griffin III. "Guardrail End Treatments in the 1990s." *Transportation Research Record 1367*. 63–75. Washington, DC: Transportation Research Board, 1992.

An attempt is made to objectively review the most important characteristics of most commercially available and widely implemented terminals or end treatments for guardrail installations. These characteristics include collision performance in the testing and roadside environments, maintenance characteristics, and costs. Field experience with these devices is reviewed. An effort is made to compare performance, use, and costs to aid interested parties in selecting the most cost-effective terminals to meet specific needs.

Jacobsen, Leslie N., Bill Legg, and Amy O'Brien. "Incident Management Using Total Stations." *Transportation Research Record 1376*. 64–70. Washington, DC: Transportation Research Board, 1992.

Have applied the use of total stations from highway surveying to the location, recording, and measurement of points related to a collision. Have found that the use of the tools can reduce the time spent at the scene while increasing the number of measurements made. More importantly, the data are stored in computer format and can be extracted by computer-aided software to help draw a recreation of the event.

Kanellaidis, George, John Golia, and K. Zarifopoulus. "A Survey of Driver's Attitudes Toward Speed Limit Violations." *Journal of Safety Research* 26, no. 1 (March 1995) 31–40.

This work investigates the attitudes of drivers in relation to speed limits in Greece. The analyses are based on data collected through completion of a questionnaire by 207 drivers. Compliance with speed limits on urban and interurban roads is compared and analyzed versus drivers' views on the relationship between speeding and the probability of road accidents. The main reasons for speed limit violations were determined through a 'self and other' approach, and the profile of speed limit offenders was investigated by use of discriminate analysis. The dominant factors underlying the various reasons for speeding are defined through factor analysis. Finally, the possible effects of the conclusions of this investigation on relevant safety campaigns are discussed.

Kaub, Alan R. "Safety Management with the Access Management and Safe Access Spacing Models." (Publisher not given) 1994.

A set of models is outlined for predicting the number of conflicts (author's definition) and the associated probable crash experience. In addition, a safety level of service scale is established for different highway types. The method requires traffic, control, and detailed geometric information as inputs.

Khisty, C. Jotin. *Assessment of Median Barriers*. WA-RD-96.1. Pullman, WA: Washington State University, December 1986.

Khorsandian, Farid, and Paul Schonfeld. *Evaluation of Impact Attenuators*. MD-86/03. College Park, MD: University of Maryland, January 1988.

Kim, Karl *et al.* "Personal and Behavioral Predictors of Automobile Crash and Injury Severity." *Accident Analysis and Prediction* 27, no. 4 (1995) 469–481.

The purpose of this paper is to develop a statistical model explaining the relationship among certain driver characteristics and behaviors, crash severity, and injury severity. Applying techniques of categorical data analysis to comprehensive data on crashes in Hawaii during 1990, the authors built a structural model relating driver characteristics and behaviors to type of crash and injury severity. The structural model helps to clarify the role of driver characteristics and behaviors in the causal sequence leading to more severe injuries. From the model, the effects of various factors in terms of odds multipliers are estimated—that is, how much does each factor increase or decrease the odds of more severe crash types and injuries. Driver behaviors of alcohol or drug

use and lack of seat belt use greatly increase the odds of more severe crashes and injuries. Driver errors are found to have a small effect, while personal characteristics of age and sex are generally insignificant. The article concludes with a discussion of our modeling approach and of the implications of the findings for appropriate traffic safety interventions and future research.

Kim, Karl, Ned Levine, and Lawrence Nitz. "The Development of a Prototype Traffic Safety Geographic Information System." *Transportation Research Record 1477.* 41–47. Washington, DC: Transportation Research Board, 1995.

A prototype geographic information system (GIS) for the analysis of motor vehicle collisions in Honolulu, Hawaii is described. An overview of GIS hardware and software is provided along with criteria utilized in the development of the Hawaii system. Mapping and spatial data sources relevant to traffic safety are described and evaluated. The usefulness of TIGER files for spatial traffic safety analyses is highlighted. Spatial analyses and potential applications of this technology in traffic safety are also outlined. Recommendations for enhancing the uses of GIS in traffic safety are offered.

Kim, Karl, and Lawrence Nitz. "Application of Automated Records Linkage Software in Traffic Records Analysis." *Transportation Research Record 1467.* 50–55. Washington, DC: Transportation Research Board, 1994.

Following a brief discussion of the underlying theory of records linkage, an automated record linkage software package called Automatch is examined along with its various applications. Features, hardware, and user requirements are discussed, and user support and interfaces are detailed and commented on. An example linking crash reports to ambulance records is described. After other possible applications and uses for this software are described, additional issues about records linkage are raised. The report is part of ongoing research carried out by the Hawaii Crash Outcome Data Evaluation System (CODES) project, funded by the National Highway Safety Traffic Administration, U.S. Department of Transportation. The purpose of the CODES Project is to link crash, EMS, hospital, claims, and long-term care data to conduct analyses on the effectiveness of seatbelts, motorcycle helmets, and other traffic safety interventions.

Koenig, Daniel J., and Zheng Wu. "The Impact of a Media Campaign in the Reduction of Risk-Taking Behavior on the Part of Drivers." *Accident Analysis and Prevention* 26, no. 5 (September 1994) 625–633.

As part of an ongoing media educational campaign to enhance pedestrian safety in the Victoria (Canada) metropolitan area, multimedia campaigns have been targeted at drivers. This paper evaluates the intersection during five separate weeks. Logistic regression analyses indicate that this media campaign produced a long-term effect of increasing drivers' yielding behaviors.

Krammes, R. A. *et al. Horizontal Alignment Design Consistency for Rural Two-Lane Highways.* FHWA-RD-94-034. Federal Highway Administration, January 1995.

Alternative approaches to defining and measuring consistency were studied. Relationships were developed between measures of consistency and expected crash experience. Data on roadways were collected using a combination of plan and profile sheets, roadway inventories, and video logs. Detailed geometrics, especially of curvature, were documented. Crash data for five years were received from police reports in each state, including review of hardcopy. Interstate differences of crash reporting were tested for and found not to be statistically significant.

Krammes, Raymond A., K. S. Rao, and O. Hoon. "Highway Geometric Design Consistency Evaluation Software." *Transportation Research Record 1500.* 19–24. Washington, DC: Transportation Research Board, 1995.

Previous research has concluded that horizontal curves whose design speeds are less than drivers' desired speeds exhibit operating-speed inconsistencies that increase accident potential, and that current AASHTO design policy lacks the ability to identify and address these inconsistencies. One step that is being taken to address these concerns is the development by the FHWA of an Interactive Highway Safety Design Model that incorporates a consistency module. A Highway Geometric Design Consistency Program has been developed to serve as a basis for this consistency module. The program is a menu-driven procedure for evaluating horizontal alignment consistency on rural two-lane highways using two preliminary models: an operating-speed-profile model and a driver-workload-profile model. This paper reviews these preliminary models, describes the menu-driven procedure for using them, and recommends future development to the models and procedure.

Kuciemba, Stephen R., and Julie Anna Cirillo. *Safety Effectiveness of Highway Design Features; Volume V: Intersections.* RD 91-048. Washington, DC: Federal Highway Administration, November 1992.

Intersections account for more than 50 percent of crashes. Experience has been increasing during the past 20 years. On the other hand, percent of fatal crashes at intersections have decreased. Describes crashes by type of intersection, channelization, and sight distance. Also examines effects of grades, passing, and wrong direction of travel as related to crashes. When designing intersection or reconstructing, need to consider all elements of intersection as a whole. Other studies regarding control show that the highest rate of crashes occur at 4-way stop controlled. In urban crashes, sight distance does not appear critical, but it is important for rural crashes. However, studies of rural intersection crashes do not show other clear cut contributors. One recommendation from review of work is that when reconstructing rural intersection, a turn lane should be added. Literature referenced through 1991.

Kulkarni, Ram B. *et al.* "Decision Analysis of Alternative Highway Alignments." *Journal of Transportation Engineering* 119, no. 3 (May 1993) 317–325.

The evaluation of alternative alignments for a proposed highway project in California required taking into account impacts on a variety of environmental and socioeconomic issues. Techniques of formal decision analysis were used to evaluate the overall impact of each alternative alignment and to rank the alignments in an ascending order of the overall impact. A multiattribute penalty function was calibrated using acceptable trade-offs among impacts on different issues as assessed by a project team of scientists and planners. Results of decision analysis suggested that one of the alternative alignments should be most preferred under a variety of assumptions and value judgments. This alternative was recommended for further analysis and inclusion in a draft environmental impact report/statement. The application of decision analysis to this evaluation problem was effective because it (1) provided a rational procedure to address multiple and often conflicting environmental and socioeconomic issues, (2) facilitated sensitivity analysis to evaluate the impact of perceived value judgements of different concerned groups on the ranking alternatives, and (3) provided a full documentation of the evaluation process.

Kullgren, *et al.* "Photogrammetry for Documentation of Vehicle Deformations - A Tool in a System for Advanced Accident Data Collection." *Accident Analysis and Prevention* 26, no. 1 (1994) 99–106.

A photogrammetric method of collection and data reduction is described for measurement of vehicle deformations. Vehicle deformations can be important measures of effectiveness for the performance of roadside safety systems.

Kullgren, Anders, Anders Lie, and Claes Tingvall. "Photogrammetry for Documentation of Vehicle Deformations - A Tool in a System for Advanced Accident Data Collection." *Proceedings, 36th Annual Conference*. 59–73. Portland, OR: Association for the Advancement of Automotive Medicine, October 1992.

Vehicle deformations are important sources for information about the performance of safety systems. Photogrammetry has developed vastly under recent years. In this study, modern photogrammetrical methods have been used for vehicle deformation analysis. The study describes the equipment for documentation and recording in the field (semi-metric camera), and a system for photogrammetrical measurements of images in laboratory environment (personal computer and digitizing tablet). The material used is based on 500 collected and measured cases. The study shows that the reliability is high and that accuracies around 15 mm can be achieved even if the equipment and routines used are relatively simple. The effects of further development using video cameras for data capture and digital images for measurements are discussed.

Kutmala, Risto. "Measuring the Safety Effects of Road Measures at Junctions." *Accident Analysis and Review* 26, no. 6 (December 1994) 781–794.

The effects of road measures implemented at main road junctions in 1984–1986 were studied on the basis of police-reported accidents that had occurred at the junction in 1983–1987. The data were obtained from an extensive junction inventory performed by the District Offices of the Finnish National Road Administration in 1988. A total of 325 three-arm and 298 four-arm junctions were included in the study. The number of types of accidents were studied at each junction both before and after the implementation of the measure. The effects of the measure were determined by comparing the observed number of accidents after the measure with the number that would have been expected to occur at the junction if the measure had not been implemented. The expected number of accidents was calculated on the basis of the observed number of accidents in the before period and the expected number of accidents as predicted by an accident model, utilizing at the same time the information on the variation of the number of accidents at similar junctions revealed by the model. Likelihood functions determined for the effects of the measures were used for studying the accuracy of the estimates of the effects. The likelihood functions can also be utilized later when new before-and-after studies are performed. Road lighting, stop signs, signal control, and lowering of the speed limit value were found to decrease the number of accidents. Through-flow junction widening, additional lanes for turning vehicles, and road widening, however, did not seem to affect the safety at junctions to any marked extent. If the regression-to-the mean effect had not been accounted for, these measures would have seemed to have a positive effect on safety. The study method also enabled the researchers to quantify the regression-to-the-mean effect. The magnitude of the regression effect was on average 20 percent (i.e., the number of accidents would have decreased by 20 percent at the junctions studied even if the measures had not been implemented). The magnitude of the regression-to-the-mean varied greatly between the different measures.

Lamm, R. *et al.* "A Procedure for Evaluating Consistency in Horizontal Alignment." Paper presented to the American Society of Civil Engineers.

Lamm, Ruediger, and Bob L. Smith. "Curvilinear Alinement: An Important Issue for More Consistent and Safer Road Characteristic." *Transportation Research Record 1445*. 12–21. Washington, DC: Transportation Research Board, 1994.

A highway alinement design process called curvilinear alinement is described. It is based on a process called relation design, which means that no more single design elements with minimum or maximum limiting values are put together more or less arbitrarily. Rather, design element sequences are formed in which the design elements following one another are subject to specific relations or relation

ranges. Quantitative criteria are given for evaluating the driving behaviors of motorists in the transitions between successive design elements as well as tuning the operating speed to the design speed for single design elements on two-lane rural roads. The curvilinear alinement can provide sounder, more consistent road alignments. The suggested procedure for modern highway design provides better quantifiable and more sophisticated criteria than those that already exist in western European design guidelines. It is recommended that curvilinear alinement design be evaluated for inclusion as a recommended design process in the AASHTO Green Book for two-lane roads.

Limotti, Brian, and Dennis Hamblet. *Evaluation of the Pavement Data Collection Guide for Highway Safety.* DTFH61-87-C-00105. Olympia, WA: Washington State Department of Transportation, February 1989. NTIS, Springfield, VA.

A case study of the ten 'high' accident locations in Washington is used to evaluate the Pavement Data Collection Guide for Highway Safety developed by the Texas Transportation Institute (TTI). Findings indicate that conditions other than substandard roadway surface were the major contributing factors to the accidents which occurred at the study locations. These factors included traffic volume, commercial roadside development, limited sight distances, inadequately controlled intersections, and alcohol usage. It was recommended that none of the analytical procedures developed by TTI be incorporated into Washington State's accident information system.

Loukes, David. "Geographic Information Systems in Transportation (GIS-T): An Infrastructure Management Information Systems Tool." *Proceedings, TAC Annual Conference, Vol. 3.* B25–B42. Quebec, 1992.

Transportation agencies maintain considerable data, both current and historic, with respect to infrastructure condition, features, and maintenance practice. A large portion of this information is referenced to the transportation network through one or (more commonly) a variety of linear referencing techniques. Unfortunately, it is not in most instances a simple matter to gain an overall appreciation of the network characteristics by creating a composite view by overlaying the various discrete 'data networks' involved. Within the last 5 years, the computer industry has seen the rapid maturity of software packages which, when combined with powerful engineering workstations, comprise an application tool kit commonly labeled geographic information systems (GIS). The growing popularity of these systems (in spite of their technical complexity) has largely been due to their ability to effectively integrate both geographic information (graphic features) and associated tabular (attribute) datasets through common indexing systems. The result of integration, coupled with powerful spatial analysis tools, has been to enable the development of effective management information systems (MIS). Transportation agencies who were eager to implement GIS applications soon discovered, however, that these systems generally lacked functionality in the integration and display of linearly referenced datasets. Since the majority of transportation data is referenced in this manner, this lack of functionality precluded effective use for most transportation purposes. Within the last year, however, GIS vendors have enhanced their packages to address the needs of transportation agencies. This paper will discuss the special GIS functional requirements which are needed for effective use by transportation agencies. Several examples of successful implementation will be presented. Suggestions will also be made as to how GIS tools, when combined with some consistent data coding standards, can be used to develop infrastructure planning applications and Management Information Systems which will ensure that the right information reaches the right people.

Loveday, J., and D. Jarrett. "Spatial Modeling of Road Accident Data." *Mathematics in Transport Planning and Control (Proceedings).* 433–446. Oxford, England: Clarendon Press, 1992.

Maher suggested that spatial autocorrelation between the mean accident frequencies at neighboring sites may account for the apparent 'migration' of road accidents from treated to untreated sites. In this paper, the data used by Boyle and Wright, together with a new data set from the City of Birmingham, are analyzed to measure the extent of spatial autocorrelation present. Theoretical spatial models which can be used to represent road accident data are examined and compared with these data sets. Common practice has been to assume that crashes at each site are statistically independent. For many reasons this is not the case, particularly traffic flows through all sites; therefore similar vehicles and drivers which can affect apparent exposure of each individual site. This hypothesis also suggests why 'migration' is found in crashes once a site has been treated. Reality was that all sites could have been considered as 'black spots.' That one site was selected was a result of chance deviation.

Luenfeld, H. *et al. Application of Positive Guidance at a Freeway-to-Freeway Connector in California, an Urban Location in Dubuque, Iowa, and a Two-Lane Rural Site in Washington.* DP-48-3. Washington, DC: Federal Highway Administration, December 1985.

Maher, M. J., and L. J. Mountain. "The Identification of Accident Blackspots: A Comparison of Current Methods." *Accident Analysis and Prevention* 20, no. 2 (April 1988) 143–151.

A recent survey reported that, in order to identify accident blackspots, most highway authorities use annual accident total (AAT), without making any allowance for any measure of exposure or the nature of the site. An alternative, and apparently improved criterion, known as potential accident reduction (PAR), has been proposed. The basis for this is that statistically significant relationships can be established between accident frequency and traffic flow for a variety of site

categories. PAR is calculated, for a site, as the difference between the observed number of accidents and the expected number for that type of site with that level of flow. If this expected frequency can be estimated accurately, then PAR should inevitably perform better than AAT, since AAT tends to identify high flow sites which do not necessarily have the potential for accident reduction. This work attempts to quantify the additional benefits to be gained by the use of PAR instead of AAT. It demonstrates that, because of the inaccuracy of the estimation of the expected frequency at a site required in PAR, it is quite possible for AAT to perform as well as, or better than PAR. If the sites, identified as blackspots, are then given some remedial treatment, the analysis of the effectiveness of this treatment must allow for what has become known as the 'regression-to-mean' effect. A method which provides a proper basis for such before and after studies is described.

Maierle, Michael J., and Mark J. Wolfgram. *Rural 2-Lane Highway Accidents and Geometrics: A Statistical Analysis.* Madison, WI: Wisconsin Department of Transportation, May 1987.

Improvements in pavement width, shoulder width, passing distance, and curvature on 2-lane roadways resulted in reduced crashes. Used a regression analysis to incorporate geometrics and produced a highway safety index (HSI) which could be used to assess the relative contribution of each of the four characteristics. For example, use of the HSI shows that increasing pavement width by 1 foot or shoulder width by 1 foot has the same effect on crash reduction.

Mak, K. K., and D. L. Sicking. *Development of Roadside Data Collection Plan.* RD 92-113. Washington, DC: Federal Highway Administration, December 1992.

Mak, King K., John G. Viner, and Linsay I. Griffin, III. "Assessment of Existing General Purpose Data Bases for Highway Safety Analysis." *Transportation Research Record 1172.* 1–10. Washington, DC: Transportation Research Board, 1988.

Safety is a continuing concern for highway officials at all levels of government. If the safety impacts of existing and proposed programs and policies for the construction and maintenance of highway systems are to be properly assessed, it is imperative that these officials be provided with the necessary supporting data. A recently completed FHWA-sponsored study critically reviewed a number of large national databases for applicability and utility to various areas of highway safety that are of prime concern to the FHWA. Conceptual alternatives that would improve or enhance the capability and utility of these databases from the standpoint of highway safety analyses were developed and evaluated for feasibility and practicality, and appropriate recommendations were made. The study results are to be considered as part of an effort to improve the capability and use of existing databases and to offer a basis for improvements in ongoing and future data collection efforts so that the information needs of highway safety analyses may be better serviced.

Manual on Classification of Motor Vehicle Traffic Accidents, ANSI D-20,1. Fifth edition. Washington, DC: American Association of Motor Vehicle Administrators, October 1989.

The manual establishes standards for fields and coding of crashes. It is comprehensive, providing for all possibilities, particularly for coding crashes. Coding is divided into driver, vehicle, and environment. Meant to set national standards.

Mason, John M., and Deborah L. Seneca. "Implementation of 'HISAM/HISAFE' Microcomputer Programs." *Microcomputer Applications in Transportation III: Proceedings of the International Conference on Microcomputers in Transportation.* New York: American Society of Civil Engineers, 1990.

McCasland, William R. "Modifying Freeway Geometrics to Increase Capacity." *Transportation Engineering Journal of ASCE* 106, no. TE6, 1980, 787–801.

McCoy, Patrick T., J. A. Bonneson, S. Ataullah, and D. S. Eitel. "Guidelines for Right-Turn Lanes on Urban Roadways." *Transportation Research Record 1445.* 130–137. Washington, DC: Transportation Research Board, 1994.

Guidelines for the use of right-turn lanes at access points on urban two-lane and four-lane roadways were developed. The guidelines define the design-hour traffic volumes for which the benefits of right-turn lanes exceed their costs. The benefits used in the analysis were the operational and accident cost savings that right-turn lanes provide road users. The operational cost savings were those associated with the reductions in stops, delays, and fuel consumption experienced by through traffic. The accident cost savings were those associated with the reduction in accidents expected from the lower speed differentials between right-turning and through traffic. The guidelines define the right-turn design-hour volume required to justify a right-turn lane as a function of the following factors: (a) directional design-hour volume, (b) roadway speed, (c) number of lanes on the roadway, and (d) right-of-way cost. Comparison with guidelines developed by others indicates that the guidelines developed in the research are within the range of existing guidelines. In addition they are more definitive than the other guidelines because they account for the effects of roadway speed and right-of-way costs.

McCoy, Patrick T., and Michael S. Malone. "Safety Effects of Left-Turn Lanes on Urban Four-Lane Roadways." *Transportation Research Record 1239.* 17–22. Washington, DC: Transportation Research Board, 1989.

As part of research conducted to develop a more definitive guide for the selection of divided and undivided sections on urban four-lane roadways in Nebraska, accident experience at signalized and unsignalized intersections on urban four-lane roadways was analyzed to assess the safety

effects of left-turn lanes. Results of this analysis are presented. Multivehicle accidents on intersection approaches with left-turn lanes were compared with those on similar approaches without left-turn lanes. The degree to which left-turn lanes on signalized and on uncontrolled approaches reduced accidents was computed. The statistical significance of the percent reductions was determined using the chi-squared test. Left-turn lanes at intersections on urban four-lane roadways were found to significantly reduce rear-end, sideswipe, and left-turn accidents. However, on the uncontrolled approaches of intersections on urban undivided roadways, left-turn lanes were found to significantly increase right-angle accidents, as well as reduce rear-end, sideswipe, and left-turn accidents.

McGee, H. W., W. E. Hughes, and K. Daily. *Effect of Highway Standards on Safety (Preliminary Draft Final Report).* Vienna, VA: Bellomo-McGee, Inc., May 1994.

This report documents and presents the results of an investigation of the relationships between safety and geometric design. To determine current practices for the application of design standards for different classes of roads, varying traffic conditions, and other factors, on-site interviews were conducted with seven states and a survey questionnaire was sent to 50 states. The findings based on the responses from 37 state highway agencies are reported. An extensive review of literature relating to accident research was undertaken to identify documented safety relationships. The results of this review is reported for design elements related to cross-section (e.g., lane width and shoulder width), alignment (e.g., degree of horizontal curvature), media (e.g., median width), and roadside (e.g., sideslope and clear zone). In addition, the best accident relationships for cross-section, alignment, median, and roadside design elements were identified, described, and applied to selected case studies which were drawn from actual highway improvement projects. These case studies illustrate how accident-design element relationships can be applied to assess the effects of changes in design on safety. The report also presents recommended future research plans that address critical deficiencies in the state-of-the-art knowledge.

McHenry, Steven, and Michael J. Wallace. *Evaluation of Wide Curb Lanes as Shared-Lane Bicycle Facilities.* MD-85/06. Baltimore, MD: Maryland DOT, August 1985.

Memmott, Jeffery L. "Simulation Results of the Highway Performance Monitoring System." *Transportation Research Record 1236.* 1–8. Washington, DC: Transportation Research Board, 1989.

This paper covers a detailed examination of the adequacy of the Highway Performance Monitoring System (HPMS) sample for making needs estimates at the district level in Texas and recommends increases in the current sample based on the results of the examination. To test the accuracy of sample sizes, a simulation model was developed to calculate the errors of a given sample size. Since the FHWA procedure uses average annual daily traffic (AADT) to calculate the required sample size, the simulation model was used to compare the accuracy of needs estimates with the assumed accuracy using AADT. It was found that, in general, the errors were larger than the assumed error range at the functional class level, but the errors decreased substantially as functional classes were aggregated. The simulation model was also used to test the usefulness of stratifying the functional classes by volume group. It was found that in most cases stratifying did improve the accuracy of the sample estimates. Further, it was found that in most cases calculating the sample at the functional class level and distributing the sample to volume groups proportionately by mileage performed better than calculating the sample at the volume group level.

Miaou, Shaw-Pin, P. S. Hu, T. Wright, A. K. Rathi, and S. C. Davis. "Relationship Between Truck Accidents and Highway Geometric Design: A Poisson Regression Approach." *Transportation Research Record 1376.* 10–18. Washington, D.C.: Transportation Research Board, 1992.

A Poisson regression model is proposed to establish empirical relationships between truck accidents and key highway geometric design variables. For a particular road section, the number of trucks involved in accidents over 1 year was assumed to be Poisson-distributed. The Poisson rate was related to the road section's geometric, traffic, and other explanatory variables (or covariates) by a loglinear function, which ensures that the rate is always nonnegative. The primary data source used was the Highway Safety Information System (HSIS), administered by FHWA. Highway geometric and traffic data for rural Interstate highways and the associated truck accidents in one HSIS state from 1985 to 1987 were used to illustrate the proposed model. The maximum likelihood method was used to estimate the model coefficients. The final model suggested that annual average daily traffic per lane, horizontal curvature, and vertical grade were significantly correlated with truck accident involvement rate but that shoulder width had comparably less correlation. Goodness-of-fit test statistics indicated that extra variation (or over dispersion) existed in the developed Poisson model, which was most likely due to the uncertainties in truck exposure data and omitted variables in the model. This suggests that better quality in truck exposure data and additional covariates could probably improve the current model. Subsequent analyses suggested, however, that this overdispersion did not change the conclusions about the relationships between truck accidents and the examined geometric and traffic variables. [See also Miaou and Lum, *Transportation Research Record 1407,* 1993, pp 11–23.]

Miaou, Shaw-Pin, and Harry Lum. "Modeling Vehicle Accidents and Highway Geometric Design Relationships." *Accident Analysis and Prevention* 25, no. 6 (1993) 689–709.

The statistical properties of four regression models - two conventional linear regression models and two Poisson regres-

sion models - are investigated in terms of their ability to model vehicle accidents and highway geometric design relationships. Potential limitations of these models pertaining to their underlying distributional assumptions, estimation procedures, functional form of accident rate, and sensitivity to short road sections, are identified. Important issues, such as the treatment of vehicle exposure and traffic conditions and data uncertainties due to sampling and nonsampling errors, are also discussed. Roadway and truck accident data from the Highway Safety Information System (HSIS), a highway safety database administered by the FHWA, have been employed to illustrate the use and the limitations of these models. It is demonstrated that the conventional linear regression models lack the distributional property to describe adequately random, discrete, nonnegative, and typically sporadic vehicle accident events on the road. As a result, these models are not appropriate to make probabilistic statements about vehicle accidents, and the test statistics derived from these models are questionable. The Poisson regression models, on the other hand, possess most of the desirable statistical properties in developing the relationships. However, if the vehicle accident data are found to be significantly overdispersed relative to its mean, then using the Poisson regression models may overstate or understate the likelihood of vehicle accidents on the road. More general probability distributions may have to be considered.

Mounce, Nancy H. and Barbara H. DeLucia. Analysis of Accident Data Quality. College Station, TX: Texas Transportation Institute, August 1991.

Mountain, Linda, and Backer Fawaz. "The Area-Wide Effects of Engineering Measures on Road Accident Occurrence." *Traffic Engineering and Control* 30, no. 7/8 (July 1989) 355–360.

Two problems exist with examining before/after treatments of high hazard locations: (1) spatial redistribution of crashes, the 'accident migration effect' and (2) random fluctuations at any given point. In second case, increases and decreases may occur at specific points in the area, but are constant over a number of points. Need to use expected frequency of crashes rather than actual frequency. Need to study using larger area. Problem with selecting neighbors to include is to prevent overlapping areas among multiple high-hazard locations. A good estimate of 'm' or mean frequency is to use similar points and compute expected frequency at all points. Then determine distribution based on gamma distribution for 'estimated m.' Shape of gamma distribution is important, but use of the gamma distribution including crashes at points including the high hazard location shows promise in evaluating changes over time.

Mullins, B. F., and C. J. Keese. "Freeway Traffic Accident Analysis and Safety Study." *Highway Research Board Bulletin 291*. 26–78. Washington, DC: Highway Research Board, 1961.

National Center for Statistics and Analysis. *National Accident Sampling System, General Estimates System, User's Manual*. Washington, DC: National Highway Traffic Safety Administration, 1990.

Manual provides a guide to the fields used to record data for the NASWS GES files.

National Center for Statistics and Analysis. *General Estimates System: A Review of Information on Police-Reported Traffic Crashes in the United States*. Washington, DC: National Highway Traffic Safety Administration, 1990.

Report of summaries of data obtained through GES in tabulations by various fields of importance to safety personnel.

Neuman, Timothy. "Safety and Operations Related to Geometrics for 21st Century Highways." *Proceedings of a Conference, American Society of Civil Engineers*. 299–309. New York: American Society of Civil Engineers, April 1988.

Research conducted in both safety and highway operations over the past 20 years must be incorporated into design of highways for next century. Key element is cost effectiveness. Need in design to address safety, design, and operational experience as an entity. Particularly important is applying knowledge of safety. Old assumptions of safety at 'any cost' are no longer practical. Cost assessment can derive greatest safety benefit for lowest expenditure. This also means that strict adherence to singular standards may not be appropriate. An example is given related to lane width and combined lane and shoulder width. The FHWA is proposing that variations in these widths can occur dependent on both the traffic volume and percentage of truck traffic. These differences can result in substantially lower construction (or reconstruction costs) for low volume roads. An important use of current technology is not simply to design the highway; rather, it needs to be used to test highway design for both safety and operations during design. Use of GIS and CADD systems can help simplify the routine computational aspects while freeing time for testing. Moreover, training needs to be adjusted to move from the technical aspects to one of incorporating testing.

Neuman, T. R., and J. C. Glennon. "Cost-Effectiveness of Improvements to Stopping-Sight-Distance Safety Problems." *Transportation Research Record 923*. 26–34. Washington, DC: Transportation Research Board, 1983.

"New Products Field Computing." *ID Systems* 15, no. 8 (August 1995) 42.

Ng, Jerry C. N., and Ezra Hauer. "Accidents on Rural Two-Lane Roads: Differences Between Seven States." *Transportation Research Record 1238*. 1–9. Washington, DC: Transportation Research Board, 1989.

Data on accidents, road characteristics, and traffic for rural, two-lane roads in seven states have been assembled. It was found that for the same amount of traffic, different states

record widely discrepant numbers of accidents. Differing types of crashes varied significantly from the curve of pooled data and best fitting line. Moreover, differences from pooled curve were in different directions for the same state but for different classifications of crashes. The discrepancy does not disappear even when roads with the same lane width, shoulder type, and terrain are examined. It is concluded that (a) data from different states should not be pooled, (b) warrants and standards based on accidents should be tailored to each state, and (c) the cause of the noted differences should be investigated. In a discussion of the paper, Zegeer and Stewart describe other factors which may be causing differences. Particularly critical is the large variations in thresholds for reporting crashes among the seven states chosen. Differences in other elements such as geography and driver behavior also can play an important role. Additionally, each state has slightly different methods of reporting events. For example, Alabama does not have a code for run-off-the-road. To compare Alabama directly with other states requires refinement of the data to interpret those crashes which could run-off-the-road. This step could refine the data to a point where sample size is too small. The discussants do believe that, with careful consideration of criteria, data can be combined among states.

Nicholson, Alan. "Indices of Accident Clustering: A Re-evaluation." *Traffic Engineering and Control* 36, no. 5 (May 1995) 291–295.

This paper discusses the need to assess the extent of accident clustering and to aid identification of the most cost-effective type of accident reduction plan, and describes an evaluation of indices of accident clustering. Interpretation of the indices, allowing for randomness in accident occurrence, is discussed. An alternative approach, involving identifying the variance of the underlying true accident rates, is described. A methodological problem with the usual form of truncated negative binomial distribution is discussed, and a new form of truncated negative binomial distribution is described.

Nicholson, Alan, and Yiik-Diew Wong. "Are Accidents Poisson Distributed? A Statistical Test." *Accident Analysis and Prevention* 25, no. 1 (February 1993) 91–97.

Examined counts of crashes using chi square and Poisson distributions. Although the chi square tests often showed better fits in individual cases, over the larger picture, Poisson appeared to be a better test. The findings held, even when individual points lie at the extremes.

Noland, Robert B. "Perceived Risk and Modal Choice: Risk Compensation in Transport Systems." *Accident Analysis and Prediction* 27, no. 4 (1995) 503–521.

A transportation mode choice analysis is performed that examines behavioral responses to perceived risk in the choice of mode for daily commute trips. This methodology provides a technique for examining, by means of disaggregate individual level data, risk-compensating effects in transportation systems. Various measures of perceived risk are examined for explaining modal choice. Other studies have described how safety regulations have resulted in increases in 'driving intensify.' This study defines one component of driving intensity to be increased probability of commuting by automobile. The results show that modal shifts occur when risk perceptions for a given mode are reduced. To demonstrate potential risk-compensating effects within the transportation system, an estimate of changes in accident fatalities due to commuting is derived through rough estimates of fatalities per person-mile traveled. It is shown that a given change in the perceived risk of commuting by automobile results in a less than proportionate change in net commuting fatalities. The relative magnitude is dependant on how objective reductions in risk translate into perceived reductions in risk. This study also shows that perceived safety improvements in bicycle transportation have an aggregate elasticity value that is greater than one. This means that bicycle safety improvements attract proportionately more people to bicycle commuting (e.g., a 10 percent increase in safety results in greater than 10 percent increases in the share of people bicycle commuting).

Northwestern University Traffic Institute. *Economic Analysis of Highway Safety Data: Site Data Book - A Compilation of Summaries and Materials Resulting from Site Visits.* DTHF61-91-C-00051. Evanston, IL: Northwestern University Traffic Institute, 1993.

The research team either visited or interviewed personnel who handle safety data in 10 states. This book presents a summary of the findings related to the following areas of interest: roadway inventory, handling the PCR, cost of managing the expanded, or shared without major software revision. The report discusses a strategy for fully implementing WACDS at WSDOT, in addition to a schedule for implementation.

Nyerges, Timothy L., and Ron. F. Cihon. *Automated Collision Diagram Production,* GC8286, Task 11. Washington State Department of Transportation, Olympia, WA, June 1989, NTIS, Springfield, VA.

O'Day, James. *NCHRP Synthesis of Highway Practice 192: Accident Data Quality.* Washington, DC: Transportation Research Board, 1993.

The report addresses quality (accuracy, precision, timeliness, and completeness) of crash data. The quality is important because data are needed to help address crash problems that need to be resolved. Multiple levels including state highway departments, legislature, federal highway safety, and medical community, as examples, are attempting to resolve many of the issues related to traffic crashes and rely on the data to assist in their decision-making. Problems associated with collecting and recording data include lack of consistency among states in what is collected along with definitions of the elements themselves. Additionally, collectors are not adequately trained. Multiple and disassociated processing of the data further reduces the likelihood of obtaining quality data.

The use of ANSI, CADRE, and NGA standards represent an attempt to help standardize what is collected and how it is defined. Although the standards may be incorporated initially in the design of state crash reports, the final product (either because of tradition or lack of trained investigators) may drop or modify the standards significantly. The synthesis includes a review of literature pertinent to the subject.

Ogden, K. W., and D. J. Howie. "Pro-Active Traffic Safety: A Study of Bridges and Culverts." *Proceedings, 15th Annual Conference.* 23–43. Australia: Australian Road Research Board, August 1990.

This paper reports on a study of pro-active traffic safety as it applies to crashes at bridges. All recorded crashes at bridges and culverts in Victoria in the 5 years, 1982–1986, were examined, and the characteristics of those crashes analyzed. The characteristics included those relating to the bridge or culvert, the approaches, the vehicles, the drivers, and the road user movements. Analysis reveals that there is only a small probability of any given bridge being associated with a crash, and that crash patterns are quite diverse. It is concluded therefore that the best approach to the development of countermeasures is likely to involve a mass application of low cost treatments, applied to a large number of bridges and culverts. Various means of treating bridge hazards are briefly reviewed, including warning and delineation, safety barriers (especially the provision of guard fences), road alignment, road environment, and bridge design and construction. Priorities for treatment of sites, based on bridge width, traffic flow, and bridge length are developed.

Panchanathan, Siram, and A. Faghri. "A Knowledge-Based Geographic Information System for Safety Analysis at Rail/Highway Grade Crossings." *Transportation Research Record 1497.* 91–100. Washington, DC: Transportation Research Board. 1995.

This paper discusses the development of an integrated, user-friendly, knowledge-based geographic information system for evaluation of safety at rail-highway grade crossings. The allocation of federal funding for safety improvements at public, at-grade rail-highway crossings is made based on the performance of states with respect to accident reduction. An earlier part of the ongoing study conducted by the authors resulted in the integration of rail-highway grade crossing safety-related data, maintained by different sources as the Federal Railroad Administration (FRA), and the Delaware Department of Transportation (Deltoid). Several empirical accident prediction models were evaluated and the WSDOT model was finally chosen as the one most suitable for the state of Delaware. A database management system was then created that allows Deltoid to create, update and modify the rail-highway database and calculate the accident hazard index based on the WSDOT model. However, the existing database management system did not have the capability for manipulation, analysis, prioritization, and access on specific user query. Also, it did not have the graphical and mapping capability to display the crossings at their actual spatial locations on the state map. Furthermore, the accident index produced by the DOT model, considering statistically significant factors, is only one of the criterion involved in accident prediction. The final decision depends on site inspection and other qualitative and judgmental information that cannot be incorporated in a mathematical model and requires expert knowledge. This paper described the conversion of exiting rail-highway crossings attribute data into a GIS acceptable format, location referencing of the crossings attribute data to their location in the graphic database, interfacing with WSDOT model and interfacing with a knowledge-based expert system for considering the qualitative and heuristic information. The TransCAD, transportation GIS application software was used and the US census TIGER database was used for the graphic database. The expert system was developed in the EXSYS shell environment.

Paniati, Jeffrey F., and Forrest M. Council. "The Highway Safety Information System: A New Tool for Safety Analysis." *1991 Compendium of Technical Papers.* 397–402. Washington, DC: Institute of Transportation Engineers, 1991.

Highway safety database was developed by FHWA and University of North Carolina Highway Safety Research Center. It is being used to help identify vehicle and roadway interactions that may lead to increased crashes or injury from crashes. Original intention was to combine data from the participating states and examine more infrequent occurrences. However, because of coding differences along with differences in definitions, the data cannot be combined. Studies are done using one state database and then examining data from other states to determine if the original findings are supported.

Paniati, Jeffrey F., and Forrest M. Council. "The Highway Safety Information System II. Applications and Future Directions." *Public Roads* 54, no. 4 (March 1991) 271–278. [see Council and Paniati December 1990].

Papleontiou, Chryssis G., Alvin H. Meyer, and David W. Fowler. *Analysis of Accident Data for Existing Databases in Texas.* FHWA/TX-92-490-3. Austin, TX: Center for Transportation Research, November 1991.

Attempt to merge and use data from crash reports and roadway surface to identify high-accident locations. Examined 94,000 reports over a 3-year span. Also obtained measures of road friction at selected sites and attempted to build a methodology to replace the traditional methods used for high-accident locations. Found no definite relationships between road friction and crashes in general.

Parke, Michael F., and Karl Kim. "Motor Vehicle Collision Reporting Systems in the United States." Paper #950382 presented at the Annual Meeting of the Transportation Research Board, Washington, DC, 22 January 1995.

Replies to a mail questionnaire sent to state transportation departments regarding how motor vehicle crash reports sys-

tems are summarized. A variety of different hardware and software packages are utilized by the agencies responsible for collection and analysis of collision data. The data elements that are required on motor vehicle crash forms and extracted into collision databases are summarized and compared to standard systems such as CADRE. A need for more standardization is evident. While new technologies such as notebook computers, automated records linkage, and other computer hardware and software offer some promise for more efficient data handling, there is a need for more standardization of data elements and coding.

Persaud, B. N. "Estimating the Accident Potential of Ontario Road Sections." *Transportation Research Record 1327.* 47–53. Washington, DC: Transportation Research Board, 1991.

Persaud, Bhagwant, and Alex Kazakov. "A Procedure for Allocating a Safety Improvement Budget Among Treatment Types." *Accident Analysis and Prevention* 26, no. 1 (1994) 121–126.

A procedure is devised and demonstrated for using safety estimation theory and benefit-cost analysis to accommodate uncertainty in crash frequency estimates within a decision-making context. The procedure allows a budget to be allocated to different programs, but ensures that the smallest net benefit is the same for all programs.

Persaud, Bhagwant, and Kornel Mucsi. "Microscopic Accident Prediction for Two-Lane Rural Roads." Paper #950473 presented at the Annual Meeting of the Transportation Research Board, Washington, DC, 22 January 1995.

Fundamental to the research presented in this paper is the use of hourly traffic volumes in regression models for estimating accident potential on 2-lane roads. Using Ontario data, a simple model form, and a regression package that allows assumption of negative binomial error structure, regression models were calibrated for the different combinations of time periods and geometric characteristics. It is shown that the effect of day/night conditions is different for single-vehicle and for multi-vehicle accidents. The refinement of the regression predictions using the empirical Bayesian estimation procedure for individual road sections is illustrated. It is shown, through a validation exercise, that the Bayesian procedure provides better estimates of accident potential that the conventional method based only on the short-term accident count of a section.

Pfefer, Ronald, Roy Lucke, and Richard Raub. *Economic Analysis of Highway Safety Data: Task Reports - Tasks A and B, Collection and Management of Highway Safety Data.* DTHF61-91-C-00051. Evanston, IL: Northwestern University Traffic Institute, December 1993.

This report addresses issues and practices associated with collecting and managing highway safety data from three sources: the PCR, highway inventory, and emergency medical services and trauma reports. It addresses how data are collected; discusses issues related to the quality of data, including an analysis of crash records maintained at the state level; and develops the methodology and formulas needed to address the costs of collecting and managing the data.

Pfefer, Ronald, Richard Raub, and Roy Lucke. *Economic Analysis of Highway Safety Data: Task Report - Task D, Evaluation of Alternative Strategies for Collecting and Managing Highway Safety Data.* DTHF61-91-C-00051. Evanston, IL: Northwestern University Traffic Institute, December 1994.

The objectives of the task included identifying candidate strategies for improving safety data collection and management by improving the quality or reducing the cost, and assessing the candidate strategies and prioritizing them. Evaluation of strategies is performed both objectively and subjectively against eight scenarios of use. The results of the evaluation are then combined with more detailed cost considerations to identify cost-benefit. Finally, strategies are combined in "packages" which take advantage of the synergy resulting from two or more strategies used in combination.

Polus, Abisha, Joseph Craus, and Moshe Livneh. "Flow and Capacity Characteristics on Two-Lane Rural Highways." *Transportation Research Record 1320.* 128–134. Washington, DC: Transportation Research Board, 1991.

Speed/volume characteristics on two-lane roads were found to be less than those suggested by the Highway Capacity Manual (HCM). Research locations showed that flow varied substantially and was highly dependent on the characteristics of the site studied. Crash statistics appear to be related closely to the flow. No single clear value appeared for hourly capacity volume. Time over which the data were collected also was important in its effect on computing flow/capacity. The single most important difference found between the research and HCM was that speeds were substantially lower at the sites studied than had been used in the HCM.

Polus, Abishai, W. J. Frith, and Nigel M. Derby. "Driver Behavior and Accident Records at Unsignalized Urban Intersections." *Accident Analysis and Prevention* 17, no. 1 (February 1985) 25–32.

Proesser, Neil A., and Stephen G. Ritchie. "Real-Time Knowledge-Based Integration of Freeway Surveillance Data." *Transportation Research Record 1320.* 40–46. Washington, DC: Transportation Research Board, 1991.

An advanced processing capability based on the use of real-time knowledge-based expert system (KBES) technology to integrate diverse types of traffic surveillance data for freeway monitoring and control purposes, particularly as part of future 'smart roads' projects, is described. One of the major functions of the prototype system is the acquisition and pro-

cessing of input data drawn from sensors and processes in the real world. The real-time nature of these processes, and the associated need for decision-making information and recommendations, places particular importance on the efficient handling of data to avoid unnecessary overloading of the expert system. The relevant types of data include traffic occupancies and volumes from loop detectors in the pavement, information on traffic conditions from closed-circuit television cameras, field reports from police officers and other official personnel, and cellular and emergency telephone calls from motorists. Emphasis is placed on the way in which the data are acquired, processed, and integrated within prototype KBES framework to achieve the objectives of the incident management tasks, specifically those of incident detection and verification. Examples are given of the implementation of these features.

Raff, M. S. "Interstate Highway-Accident Study." *Highway Research Bulletin 74*. Washington, DC: Highway Research Board, 1953.

Rajalin, Sirpa. "The Connection Between Risky Driving and Involvement in Fatal Accidents." *Accident Analysis and Prevention* 26, no. 5 (September 1994) 555–562.

The connection between risky driving and involvement in fatal accidents was investigated in two studies using two data sets. The first study compared the recorded offenses of 615 drivers involved in fatal accidents with a sample of drivers randomly selected from driver records. The second study compared the record offenses of 143 drivers stopped by the police for risky driving with the prior records of control drivers stopped at the same locations. The drivers involved in fatal accidents and the drivers stopped for risky driving had violated traffic regulations more often than other drivers. Those responsible for causing fatal accidents as well as involved but nonculpable drivers had previously been convicted of traffic offenses more often than other drivers. Among the fatal-accident drivers, those involved in running-off-the-road accidents had accumulated the largest number of traffic offenses. There appears to be a particular link between the age and the prior offense rate of the two risk groups. For under-35-year-old drivers, the offense rates (offense/million kilometers) of those stopped for risky driving and those involved in fatal accidents were about the same. For over-35-year-old drivers, the drivers stopped for risky driving had accumulated many times more speeding offenses than those involved in fatal accidents. Unlike the other groups, the offense rate of those stopped for risky driving does not decrease with age.

Ranney, Thomas A. "Models of Driving Behavior: A Review of Their Evolution." *Accident Analysis and Review* 26, no. 6 (December 1994) 733–750.

This paper reviews models that emphasize the cognitive components of driving behavior. Studies of individual differences have sought predictors of accident histories. Typically low correlations and reliance on post hoc explanations reflect theoretical deficiencies and problems with the use of accident measures. Motivational models emphasize transient, situation-specific factors rather than stable, individual predictors. However, neither testable hypotheses nor suitable methods have been developed to study situational factors and motives that influence driving. More recent modes have incorporated a hierarchical control structure, which assumes concurrent activity at strategic, maneuvering, and operational levels of control. At the same time, automaticity has emerged as a central construct in cognitive psychology. All activities are assumed to combine fast, automatic components with slower, more deliberate, controlled processing. It is argued that identifying the situational factors that increase drivers' uncertainty and thus trigger a shift in attention from automatic to controlled processing will help integrate concepts of automaticity and motivational models. Finally, recent theorizing has suggested that errors associated with the inherent variability of human behavior may be more important to roadway crash causation than systematic errors, which are attributable to the known limits of the human information-processing system. Drivers' abilities to recover from errors may also be important to crash causation. It is concluded that the hierarchical control structure and theories of automaticity and errors provide the potential tools for defining alternative criterion measures, such as safety margins, and developing testable theories of driving behavior and crash causation. Two examples of models that integrate information-processing mechanisms within a motivational framework are described.

Ranney, Thomas A., and Lucinda A. Simmons. "Emerging Trends in Roadway Transport and Their Impact on Highway Safety." *Transportation Quarterly* 47, no. 4 (October 1993) 561–572.

Incompatibilities among drivers, vehicles, and roadway systems lead to problems with congestion and safety. Estimate costs show source of congestion and present current solutions to reduce the costs. Section related to deterioration of the roadway infrastructure and its costs. Also suggests that increasing number of construction zone related deaths, greater than 700 per year, are direct result of deterioration. Looks at intelligent vehicle and highway systems for some relief to congestion and to provide a means for congestion pricing.

Rao, Kant, Shelly J. Mergins, and Kenneth Mitchell. "Guidelines for Executive Management Information Systems in State DOTs." *Transportation Quarterly* 47, no. 2 (April 1993) 185–206.

Provides description of how a management information system can be integrated into the scope of work performed by a DOT. Requires linkages among various systems. Should rely heavily on menus and graphical user interface in order to encourage executive management to use the system.

Raub, Richard A. "Identifying High-Hazard Locations for Pedestrian and Bicycle Crashes." Washington, DC, (Publisher not given) January 1996.

Alleviation of pedestrian and bicycle crashes has not employed analyses of high-hazard locations based on exposure measures similar to what has been done for vehicular crashes. The difficulty results from the lack of an adequate measure for pedestrian and bicycle crash exposure. Neither the number of vehicles using the roadway nor the pedestrian or bicycle volume has shown adequate relationship to crashes involving these groups. Moreover, pedestrian and bicycle volumes are not gathered except for isolated locations within a city. This research explores a method of using population which is readily available from the U.S. Census as the basis for computing rates. These rates are assigned to roadway segments and with the aid of geographic information systems are placed on a map of the city. This process allows persons involved with highway safety to view a map and rapidly pinpoint locations which may be experiencing abnormal levels of crashes.

Raub, Richard A., Ronald C. Pfefer, and Roy E. Lucke. *Task Report: Issues and Noteworthy Practices Related to Highway Safety-Data Collection and Management.* Evanston, IL: Northwestern University Traffic Institute, February 1994.

During the course of identifying how highway safety-data were gathered and managed, a number of issues and noteworthy practices implemented at sites throughout the nation were documented. This paper describes the issues and shows how noteworthy practices are designed to address some of them. Framework for the discussion is that portion of the highway safety information system related to collecting and managing data.

Raub, Richard A., Ronald C. Pfefer, and Roy E. Lucke. *Highway Safety Data: Costs, Quality, and Strategies for Improvement Research Report.* Evanston, IL: Northwestern University Traffic Institute, August 1995.

This research report summarizes the work performed for the FHWA project, "Economic Analysis of Highway Safety Data." The project was designed to (1) determine the costs currently associated with collecting and managing highway safety-data with emphasis on crash reporting, (2) determine the quality of the data collected from the crash report, roadway inventory, and medical documents, (3) identify issues which affect the collection, storage, and use of the data from the three sources, and (4) recommend strategies for reducing costs, improving quality, and resolving issues which affect the collection, management, and subsequent use of the data. The focus is on collecting and recording data. How the users employed the data generally was outside the scope of the study. The report examines the highway safety system. It emphasizes that portion of the system which assists decisionmakers and was limited to collection and management of safety data as opposed to data used for case management.

Reinfurt, Donald W., C. V. Zegeer, B. J. Shelton, and T. R. Neuman. "Analysis of Vehicle Operations on Horizontal Curves." *Transportation Research Record 1318.* 43–50. Washington, DC: Transportation Research Board, 1991.

A study was conducted to quantify the effects of horizontal curve features on such operational variables as changes in vehicle speeds and vehicle encroachments over the centerline and edge line. This information was considered important in determining curve design criteria that would lead to effective safety and operational improvements at current curve sites. The data included geometric, traffic, and operational measures from a data base of 78 curve sites in New York State. Various statistical procedures were used, including linear regression analyses, analyses of operations by differing groups of geometric conditions, residual analyses, and locally weighted nonparametric regression. It was found that, as curves become larger, there is a proportionally greater increase in speed reduction and edge line encroachments on the inside lane (i.e., the lane on a curve where the motorist must steer to the right). Centerline encroachments in the outside lane increase more drastically than those on the sharper curves to the right. These findings support the contention of drivers cutting the curve short, which can result in run-off-road crashes on the inside of the curve as well as head-on and opposite-direction-sideswipe crashes with oncoming motorists. Appropriate curve design guidelines are discussed that may help to minimize these operational and potentially accident-related trends.

Report from the Conference on the Collection and Analysis of State Highway Safety Data. February/March 1990. PB90-259599. Washington, DC: National Highway Traffic Safety Administration, 1990.

Analysis of state data in the Highway Safety Program Management shows that few states take full advantage of available data in developing programs for highway safety. The data need to be integrated into safety planning.

A Report on Highway Safety Devices for the Texas Legislature, 69th Session. College Station, TX: Texas Transportation Institute, January 1985.

Richards, S. H., T. D. Sullivan, and R. A. Margiotta. *National Governors' Association Truck Accident Data Collection Program Instructor's Manual.* FHWA/SA 92-030. Knoxville, TN: University of Tennessee, November 1991.

The traffic accident data currently available for commercial carriers is insufficient to develop policy and programs designed to reduce crashes and their severity. The defect stems principally from the lack of common definitions (e.g., bus, truck, trailer, and methods used to collect and record crash data). The National Governors' Association (NGA) program is designed to standardize definitions, criteria for denoting which crashes require data collection and reporting, the fields of data to be collected, and codes to be used within

those fields. Common fields and codes are critical if data are to be aggregated on a national basis. The authors provide both a report and an instructor's manual for training personnel in using the NGA criteria.

Roadside Design Guide, 1989. Washington, DC: American Association of State Highway and Transportation Officials, 1989.

Ross, Hayes E. Jr. "Evolution of Roadside Safety." *Transportation Research Circular 435.* 5–16. Washington, DC: Transportation Research Board, January 1995.

Author first outlines the history of progress made in the improvement of roadside safety since the 1960s. Includes references to seminal papers, federal acts, and specific tasks (such as initial development of crash cushions). Most important linkage to all efforts has been concept of a 'forgiving roadside.' Paper includes specific design concepts introduced with particular emphasis on hardware. It also presents issues related to evaluation of the concepts, to installation and maintenance, and to future concerns.

Sayed, Tarek, Gerald Brown, and Francis Navin. "Simulation of Traffic Conflicts at Unsignalized Intersections with TSC-Sim." *Accident Analysis and Prevention* 26, no. 5 (September 1994) 593–607.

This paper describes a traffic conflicts computer simulation model and graphic display for both T- and 4-leg unsignalized intersections. The goal of the model is to study traffic conflicts as critical-event traffic situations and the effect of driver and traffic parameters on the occurrence of conflicts. The analysis extends conventional gap acceptance criteria to describe driver's behavior at unsignalized intersections by combining some aspects of gap acceptance criteria and the effect of several parameters including driver's characteristics such as age, sex, and waiting time. The effect of different traffic parameters such as volume and speed on the number and severity of traffic conflicts is also investigated. The model is unique insofar as it uses a technique of importance sampling and stores the traffic conflicts that occur during the simulation for later study. A graphical animation display is used to show how these conflicts occurred and what the values of critical variables are at the time. Model results were evaluated against previous work in the literature and validated by using field observations from four unsignalized intersections. The simulation results correlated reasonably well with actual conflict observations and should prove useful for assessing safety performance and feasible solutions for other unsignalized intersections.

Sayers, Michael W., and Carrie Mink. "Integration of Road Design with Vehicle Dynamics Models Through a Simulation Graphic User Interface (SGUI)." Paper #951084 presented at the Transportation Research Board, Washington, DC, 22 January 1995.

The Federal Highway Administration has undertaken a long-term program to develop an Interactive Highway Safety Design Model (IHSDM) that systematically considers safety of roadway and roadside design elements in creating cost-effective highway design alternatives. Among other things, the IHSDM is planned to employ vehicle dynamics models to determine performance of various designs with respect to use by a variety of car and truck types. This paper describes a simulation graphical user interface (SUGI) that integrates vehicle dynamics simulation tools, input data, and graphical visualization of results. The SGUI design makes use of modern (1990s) computer hardware and software, running under UNIX/X-Windows, or Macintosh. The interface almost eliminates the need for computer expertise: most information is shown in a graphic context, and 'what if?' options are selected by clicking buttons and selecting items from pop-up menus. The SGUI is organized as a database of vehicles, vehicle parts, vehicle inputs, and simulation results. The organization makes it easy for users who are not experts in all aspects of vehicle dynamics to apply existing descriptions from the libraries. Simulation programs are run automatically by clicking buttons on the screen, and results are viewed graphically. The vehicle dynamics module will be integrated with road design software through the use of vehicle performance signatures. The signatures can be combined with alignment and superelevation design data to rapidly generate predictions of vehicle response versus station number. A key feature of the SGUI design is that it can be easily extended in the coming years to fully add the planned functionality IHSDM.

Shafer, Mark, Quinn Brackett, and Raymond A. Krammes. "Driver Mental Workloads as a Measure of Geometric Design Consistency for Horizontal Curves." Paper #950706 presented at the Transportation Research Board, Washington, DC, 22 January 1995.

Previous research has suggested that driver mental workload is a promising measure of geometric design consistency. One strength of driver workload as a measure of consistency is that, in theory, it can be applied to any geometric feature, unlike operating-speed reduction, the principal alternative measure of consistency, which is limited in application to horizontal, and possibly vertical, alignment. The weakness of driver workload is that it has been difficult to measure. Existing procedures for estimating the workload associated with roadway geometry features are based on subjective appraisals, which makes them difficult to validate. This paper documents a study that collected objective measurements of driver workload at horizontal curves using the vision occlusion method and developed a workload-profile model for evaluating design consistency. The results indicate that driver workload, measured by the vision occlusion method, increases approximately linearly as degree of curvature increases. Workload profiles begin increasing on approach tangents and peak near the beginning of a horizontal curve. It was concluded that the vision occlusion method was an appropriate method for

estimating driver workload on horizontal curves and that additional research should further develop the method and test its application for measuring workload at other roadway geometry features.

Shankar, Venkataraman, Fred L. Mannering, and Woodrow Barfield. "Effect of Roadway Geometrics and Environmental Factors on Rural Accident Frequencies." Paper #950229 presented at the Transportation Research Board, Washington, DC, 22 January 1995.

This paper explores the frequency of occurrence of highway accidents on the basis of a multivariate analysis of roadway geometrics (e.g., horizontal and vertical alignments), weather and other seasonal effects. Based on accident data collected in the field, a negative binomial model of overall accident frequencies is estimated along with models of the frequency of specific accident types. Interactions between weather and geometric variables are proposed as part of the model specifications. The results of the analysis uncover important determinants of accident frequency. By studying the relationship between weather and geometric elements, this paper offers insight into potential measures to counter the adverse effects of weather on highway sections with challenging geometrics.

Sharp, Kevin. "Seeing Another Dimension of 2-D." *ID SYSTEMS* 8, August 1995 (1915) 14.

Sharp, Kevin. "Voice Data Entry's Hands-Free Approach." *ID SYSTEMS* 7, July 1995 (1915) 24.

Shefer, Daniel. *Congestion, Air Pollution and Road Safety in Urban Areas*. Publication No. 93-087. Technion, Israel Institute of Technology: Transportation Research Institute, June 1983.

Factors for consideration in developing roadway policy are discussed. Among them is the concept of a relationship between volume-capacity ratio and number of fatalities. Implications of this concept are discussed.

Shefer, Daniel. "Congestion, Air Pollution, and Road Fatalities in Urban Areas." *Accident Analysis and Prevention* 26, no. 4 (1994) 501–509.

The continuous rapid growth in vehicle miles traveled coupled with the rapid increase in traffic congestion on highways of virtually every large urban area explain a major portion of the observed deterioration of urban air quality. To halt this deterioration and to secure safe and healthy environments and improve the quality of life in our cities, it is useful to initiate and implement programs that treat jointly traffic congestion, air quality, and road safety. Market-based strategies, driven by price mechanisms, have been proposed as the best and most efficient way to decrease traffic congestion and to reduce vehicle emission. Congestion pricing, emission fees, reducing emissions of high-polluting vehicles, and introducing more efficient vehicle and/or fuel technologies are not mutually exclusive strategies and therefore they can be employed jointly within an overall strategy. In view of the conflicting objectives that may exist between improving urban air quality and reducing road fatalities and traffic congestion, it is of great importance to investigate thoroughly these functional relationships. For example, improving capacity can reduce congestion, but because it attracts more vehicles, it can also increase fatalities. The results of such studies will help decisionmakers identify the 'socially optimal level of congestion' that will yield the highest net social benefit.

Sicking, Deal L. *et al. Development of New Guardrail End Treatments*. TX-89/404-1F. College Station, TX: Texas Transportation Institute, October 1988.

Tested two types of guardrail end treatments through use of filming and analyzing vehicular crashes into the rails. The guardrail extruded terminal offered the best improvement over present conditions in cost, design, and impact performance.

Simkowitz, Howard J. "Geographic Information Systems: An Important Technology for Transportation Planning and Operations." *Transportation Research Record 1236*. 14–22 Washington, DC: Transportation Research Board, 1989.

A geographic information system (GIS) is a computerized database management system for the capture, storage, retrieval, analysis, and display of spatial (i.e., locationally defined) data. The purpose of this paper is to explain why GIS technology is important to transportation professionals, describe how a number of transportation agencies are using GIS, and provide insight on how to participate in this technology. Transportation agencies are still in their infancy with respect to exploiting the power and possibilities offered by GIS technology. The usefulness of spatially integrated data to transportation is examined and the distinction is made between GIS and other database systems that use spatial data. The benefits of GIS are summarized, and examples of GIS activities at the FHWA and state highway agencies are described. Sources for digital geocoded data, including U.S. Geological Survey digital line graphs and Bureau of the Census topologically integrated geographic encoding and referencing files, are discussed.

Site Data Book: A Compilation of Summaries and Materials Resulting from Site Visits. DTFH61-91-C-00051. Evanston, IL: Northwestern University Traffic Institute (unpublished), October 1993.

Information gathered during interviews and personal contacts with state highway and state safety data personnel in selected states throughout the United States. It also includes summaries of noteworthy practices related to improving either the gathering of roadway and safety data or its quality.

Smith, Gregory C. "Discussion of Photogrammetry for Documentation of Vehicle Deformations - A Tool in a System for Advanced Accident Data Collection." *Proceedings, 36th Annual Conference*. 75–82. Portland, OR: Association for the Advancement of Automotive Medicine, October 1992.

The aspects of photogrammetry presented in the paper are not disputed. A brief discussion of past and present pursuits of photogrammetry in automobile accident data collection are given, along with a list of references. Some unsupported statements about accident severity measurement and passenger safety are challenged.

Spring, Gary S. *et al.* "Testing, Verification, and Validation of Expert Systems." *Journal of Transportation Engineering* 117, no. 3 (May 1991) 350–361.

This paper discusses how an expert system can be tested, verified, and validated. A prototype expert system, the hazardous location analyst (HLA), which analyzes high-accident locations, is used to illustrate the evaluation process and to examine the various aspects of testing, verification, and validation. Identified were several key issues that must be addressed when evaluating an expert system: problem complexity, no 'correct answer,' the problem of defining expert-level performance, and considerations in knowledge-base refinement. The paper also suggests ways in which to make comparisons between expert-system and human-expert inferences so that ease of use, knowledge-base adequacy, and completeness may be examined. The paper further suggests that although some quantitative performance measures are useful for the evaluation process, a qualitative evaluation is perhaps also appropriate for many aspects of these kinds of systems.

Spring, Gary S., and Joseph Hummer. "Identification of Hazardous Highway Locations Using Knowledge-Based GIS: A Case Study." Paper #950512 presented at the Transportation Research Board, Washington, DC, 22 January 1995.

This paper describes work conducted at North Carolina A&T State University and North Carolina State University, which used the increased capabilities offered geographic information systems (GIS), along with the detailed mapping (which contains highway features and geometrics) available for Guilford County, North Carolina, to demonstrate the use of engineering knowledge regarding accident causation to identify hazardous locations. The general approach taken was that of the pilot study where a subset of information is used to demonstrate how a new technology (in this case GIS) may be used to solve a particular problem or problems. The mapping data available from the county, along with various older data files, the MapInfo GIS, and North Carolina's Accident Records System (ARS) were used to conduct the Study. The project provided valuable information regarding the limitations and advantages of using engineering knowledge about accident causation for identifying 'hazardous highway locations' and demonstrated the utility and difficulties of the GIS applied to ARS. This paper focuses on the overall approach and discusses difficulties associated with implementation.

Squires, Christopher A., and Peter S. Parsonson. "Accident Comparison of Raised Median and Two-Way Left-Turn Lane Median Treatments." *Transportation Research Record 1239*. 30–40. Washington, DC: Transportation Research Board, 1989.

It is accepted that the installation of a median will reduce accident occurrence along a previously undivided road. This report provides an accident comparison of raised medians and continuous two-way left-turn lanes used as median treatments on four- and six-lane roads. A statistical comparison of accident rates for the two section types and regression equations to model expected accident experience for each section were developed. Four- and six-lane roadway study sections in Georgia were analyzed separately. The accident rate of raised medians was found to be lower than the rate of two-away left-turn lanes for both four-and six-lane roadway sections. Regression equations were developed for raised median and two-way left-turn lane sections, four- and six-lane sections, total and mid-block accidents, and accidents per million vehicle miles, and accidents per mile per year. Tables of expected accident rate values were developed from the regression equations. On the basis of expected total accidents per million vehicle miles, the tables indicated that for four-lane sections, raised medians and a lower accident rate over the range of data studied. Results from six-lane sections were mixed. The regression equations indicated that raised medians would have lower accident rates for most conditions. However, two-way left-turn lanes had a lower accident rate where few concentrated areas of turns, such as signalized intersections and unsignalized approaches, existed.

St. John, Andrew, and Douglas W. Harwood. "Safety Considerations for Truck Climbing Lanes on Rural Highways." *Transportation Research Record 1303*. 74–82 Washington, DC: Transportation Research Board, 1991.

Data on the speed profiles of trucks on sustained upgrades can be combined with safety estimates to quantify the increased accident rates caused by slow-moving trucks and the changes in accident rate with distance up the grade. Truck performance and speed data were taken from recent field measurements and were evaluated using the truck performance equations presented in *NCHRP Report 185*. The effect of speed differences on accident rate is based on the relationships developed by Solomon. The results show that there is a pronounced increase in accident rates of passenger cars and trucks in the traffic stream only when a sizeable portion of the truck population falls to speeds of 22.5 mph or less. The results indicate that, from a safety standpoint, there is little apparent need for truck climbing lanes on moderate upgrades (2 percent) or in the first portion of steeper upgrades. However, the results must be interpreted cautiously in light of limitations in the Solomon data that were found during the analysis. In particular, the Solomon data do not show how

accident involvement rates change within the very important speed range from zero to 22.5 mph, and these data may represent sections with more intersection- and driveway-related accidents than would typically be found on a sustained grade. Further research is needed to quantify relationships between speed difference and accident involvement rates that are specifically applicable to sustained grades.

Stamatiadis, Nioforos, William C. Taylor, and Francis X. McKelvey. "Older Drivers and Intersection Traffic Control Devices." *Journal of Transportation Engineering* 117, no. 3 (May 1991) 311–319.

This paper examines the relationship between accidents of elderly drivers and intersection traffic control devices. The data was analyzed in two stages, and the analyses were performed using the induced exposure method, in which the exposure to an accident is defined as the probability of the driver not being cited for the accident occurrence. First the conditions under which elderly drivers have higher accident involvement were determined and then statistical tests were conducted to compare these conditions to the accident involvement of elderly drivers which is higher than that of the other drivers under certain circumstances. This study documented the fact that elderly experience difficulty as the complexity of the design and traffic control device application increases. To reduce the accident rates of elderly drivers and improve safety measures that affect them, modifications of the licensing testing and procedures and implementation of driver training programs for the elderly are suggested.

Sullivan, Edward C., and Hsu Chaung-Ing. *Accident Rates Along Congested Freeways-Final Report.* Edited by Hsu Chaug-Ing. UCB-ITS-RR-88-6. University of California at Berkeley, Institute for Transportation Studies, March 1988.

A set of relationships is derived relating traffic congestion and selected physical design variables to crash experience. It was found that accident rates, during queue conditions, are usually two to three times those when no queues exist, for a wide range of section geometrics and other underlying conditions. Physical and traffic variables needed include length of section, number of lanes, number of ramps, auxiliary lanes, peak hour flow, percent trucks, restricted site distance, and significant grades.

Sullivan, T. Darcy. "Technical Data Collection Following a Highway Traffic Accident Why, When, and How." *1992 Compendium of Technical Papers.* 189–193. Washington, DC: Institute of Transportation Engineers, 1992.

Each crash has the potential for tort claims. Must have an established method to identify and document data regarding the crash and crash scene soon after the incident has occurred. Too often, the defendants (i.e., highway engineers) have no knowledge that a claim has been filed until long after the event. Not only has the plaintiff had time to develop a strong case, but evidence about the crash which may have been valuable for the defense has been lost. Author addresses the type of crashes most likely to result in a tort action. Any crash that involves a fatality or serious (life threatening or disabling) injury should be considered as having a potential for action. However, the author also adds some other conditions where the engineering representatives (or the state) should investigate regardless of severity: (a) where media or police 'suggest' a deficiency in the roadway, particularly if the issue has arisen on previous occasions, (b) higher than average history of crashes, (c) outdate designs particularly where correction could have been made at a relatively low cost, and (d) low shoulders which have existed over a 'long' (undefined term) period. When a crash meets any criteria, representatives need to visit the site and collect appropriate data. They should follow a standard form. Opinions, observations, and conclusions are not to be included. Recommends taking photographs from multiple perspectives and including all evidence of the crash (e.g., skid marks, points of impact, along with the vehicle itself).

Taylor, James I., and Harold T. Thompson. *Identification of Hazardous Locations.* FHWA-77-81. Federal Highway Administration, December 1977.

The study developed a Hazardousness Index which consisted of the following variables: number of crashes, crash rate, crash severity, volume/capacity ratio, sight distance, traffic conflicts, erratic maneuvers, driver expectancy, and information system deficiencies. These variables suggest data needs that may be appropriate to the current study.

Taylor, W. C., and S. Malik. *Accident Datafile Accuracy.* UMTRI-74928. East Lansing, MI: Michigan State University, College of Engineering, 1987.

Review of police coding errors for some fields. The study was initiated because it had been observed that about 30 percent of the single-trailer combinations were coded (in the Michigan State Police files) with incorrect codes.

"Technology Focus." *Government Technology* 8, no. 8 (August 1995) 1+.

Terhune, Kenneth. *Contributions of Vehicle Factors and Roadside Features to Rollover in Single-Vehicle Crashes.* DTNH22-87-D-47174. Buffalo, NY: CALSPAN, March 1991. NTIS, Springfield, VA.

This exploratory study examined single-vehicle crashes from the National Accident Sampling System (NASS), to suggest how vehicle factors and roadside features interact in generating rollovers. Crashes were identified for a 1000-case sample stratified on vehicle stability factor (half the track width divided by center of gravity height) and wheelbase. Hard copies of the NASS cases were obtained and details of the crash dynamics and roadside features were recorded on a coding form by an experienced accident investigator. The

data were then entered into an automated database. Due to the exploratory nature of the study and the small numbers in the subsamples, the data were analyzed in unweighted form. Consequently, the study should be viewed as heuristic: the results cannot be generalized and taken as representative of the national population of cars and light trucks in accidents. Findings were (1) roadside features with the highest rollover rates of contacting vehicles were side slopes and ditches; (2) vehicle factors were related to overturn rates mainly with the most hazardous roadside features; (3) the combined data for the cars and light trucks of the sample indicate that the overturn rates were inversely related to the stability factors (the separate data did not have this general trend, but reliability of the stability factor data may have been a problem); (4) wheelbase was inversely related to rollover rates; (5) when controlling for wheelbase and stability factor, light trucks had substantially higher overturn rates; and (6) wheelbase and vehicle type were related to pre-cash vehicle modes (skidding, spinning, etc.), which in turn were related to rollover rates. Recommendations included the need for reliable stability factor data.

Todd, Kenneth. "Should Yield Stop?" *ITE Journal* (May 1993) 36–41.

The author reviews conclusions found in *NCHRP Report 320* (1989) regarding warrants and other standards for differentiating between stop and yield-controlled intersections. Author suggests that warrants for yield are too restrictive and limit use unnecessarily. Use of sight distances are important, but argument of having specific sight distances 'x' feet from the intersection based on approach speed may not always be valid. In many cases, the number of vehicles approaching on the minor street may be great enough, or configurations such, that the actual point of decision lies at the intersection. Moreover, simply taking into account restrictive sight distance at the intersection itself may also be inadequate depending on the crossing (major road) volumes. In many cases, shorter gaps can be accepted when the vehicle is rolling than when the vehicle has come to a complete stop and then must accelerate into the stream. The author argues that restrictions on movement should derive from real risk, not speculation, and that risks must be explained clearly to the public. This need is particularly important in light of multiple studies which continue to find that drivers fail to comply with stop signs (often using them as yield signs). Primary reasons for noncompliance appear to be (a) signs cause substantial inconvenience to drivers and (b) the signs are unduly restrictive. Both arguments can be addressed more adequately by careful study and application of the results to the erection of signs at intersections.

Tom, G. K. J., and K. L. Elcock. *Truck Speeds Along Downgrades in California.* CA/T0-88/1. Sacramento, CA: California Department of Transportation, February 1988.

Tests performed on freeways at different grades and lengths, and at different speeds. No definite relationship found between speeds and rate or length of downgrade. Characteristics related to location of each downgrade appeared more important than the tested items.

Tornros, Jan. "Effect of Driving Speed on Reaction Time During Motorway Driving." *Accident Analysis and Prediction* 27, no. 4 (1995) 435–442.

Effects of driving speed (70, 90, and 110 km/h) on subsidiary auditory reaction time were studied during car driving on a motorway with a speed limit of 110 km/h. Driving distance was held constant at about 200 km. Twenty-four subjects participated in a related-measurement design. Reaction time was found to be slower at 70 km/h than at 110 km/h. Before and after the driving session, the subjects' simple reaction time, mood, and alertness were measured in the laboratory. No significant differential after-effects of driving speed were found on any of these measures, although subjects rated themselves as less energetic towards the end of their journey when driving at the former to the latter speed.

Transportation Research Board Circular 435. "Roadside Safety Issues." Washington, DC: Transportation Research Board, January 1995.

Troxel, Lori A., Malcolm H. Ray, and John F. Carney, III. *Accident Data Analysis of Side-Impact, Fixed Objects.* DTFH61-88-R-00092. Nashville, TN: Vanderbilt University, May 1994. NTIS, Springfield, VA.

The results of a study of accident data of side-impact, fixed-object collisions are presented in this report. The Fatal Accident Reporting System (FARS) was used to determine basic characteristics of this type of collision such as seating position of fatally injured occupants, roadway type, surface conditions, and vehicle weights. The National Accident Sampling System (NASS) was used to obtain data about accidents at all levels of severity. In addition, effects of roadside objects such as guardrails, and impact deformations in resulting collisions were examined using the NASS data. Characteristics of side-impact, fixed-object accident such as location of impact, body region injured, and injury sources also were studied. Results of vehicle-to-fixed-object crashes were compared to vehicle-to-vehicle crashes. Most crashes that resulted in injury involved striking a narrow object. Curved alignment, but dry surface, was most likely to be involved as a roadside element. Striking guardrail ends and culvert head walls resulted in the most fatalities. Of special interest is that while side-impact crashes represented 33 percent of crashes studied, they accounted for more than 50 percent of serious injury/fatality crashes.

Turner, Daniel D., and Cecil W. Colson. "Accident Data as a Tool for Highway Risk Management." *Transportation Research Record 1172.* 11–22. Washington, DC: Transportation Research Board, 1988.

Transportation agencies at all levels of government have experienced a rash of suits involving alleged negligence. The devastating increase in the number of suits and in the magnitude of financial losses has been overwhelming to many of these transportation agencies. In an effort to minimize these losses, many agencies have organized 'risk management' programs. The risk in this case is the probability that the agency will be sued following a highway accident. If all highway accidents could be eliminated, the risk would become zero. Because this is impossible, the next most desirable option is to reduce the number of accidents (especially high-severity collisions) and thus reduce the probability of being sued. Accident data offer an excellent technique for reducing risk by identifying those sites that are of greatest risk to the motorist and thus most deserving of safety treatment. In this paper, several innovative accident data programs are described, and sample computer listings of accident data for several of them are presented. The federal aid safety program, accident inventory listings, high-accident locations, wet pavement accidents, daylight-dark accidents, roadway defect investigations, high-exposure accidents, railroad crossings, roadside objects, and bridge collisions are a few of the topics included.

Turner, Daniel S., and Edward R. Mansfield. "Urban Trees and Roadside Safety." *Journal of Transportation Engineering* 116, no. 1 (January 1990) 90–103.

This paper describes a research project performed as part of a clear zone implementation program for Huntsville, Alabama. A literature review and a field investigation program were the two major components of the project. Investigators visited the sites of 164 urban tree accidents to identify their characteristics. Time of day, day of week, accident severity, roadway geometry, pavement surface condition, lateral distance from the pavement to the tree, tree size, and tree density were among the characteristics investigated. Among the major finds were that there were strong similarities between urban and rural tree collision patterns, but urban accidents were less severe; the outside of horizontal curves was highly overrepresented; and 80 percent of the collisions were within 20 ft of the pavement edge. Recommendations were provided to city ordinances and operating procedures for future tree planting. A plan was also devised for retrofitting the clear zone concept to existing trees along the city streets.

Twomey, James M., Max L. Heckman, and John C. Hayward. *Safety Effectiveness of Highway Design Features; Volume IV: Interchanges.* RD 91-047. Washington, DC: Federal Highway Administration, November 1992.

Examines crashes on interchanges which are providing movement between two or more grade-separated roadways. Studies of both vertical and horizontal alignment show that the predominate feature related to crashes is horizontal alignment. Left-side ramps have substantially higher crash experience than other forms of interchange. Clover-leaf also has relatively high experience. Best experience found on diamond type ramps. Truck crashes on ramps likely to be rollover and jackknife. Such crashes most likely on clover leaf type interchanges. Within interchange area, deceleration lanes have highest crash experience. No correlation between capacity and safety. Interchange reconstruction generally results in marked improvement in crash reduction. Literature reviewed through 1991.

Uber, C. B. "Accidents at Railway Level Crossing in Victoria, 1975 to 1988." *Proceedings, 15th Annual Conference.* 107–122. Australia: Australian Road Research Board, August 1990.

This paper examines the trends and characteristics of road users involved in accidents at railway level crossings for the period 1975–1988 in Victoria. Total casualty accidents have decreased; however, this decrease is entirely in motorized vehicle/train accidents as boom barriers or flashing lights have been installed at crossings with the greatest exposure and accident history. Casualty accidents with trains involving pedestrians, bicycles, and horses have increased slightly in this period. Differences in the types of level crossing accidents in Metropolitan Melbourne and the rest of the state are examined.

"Uniformity in Motor Carrier Reporting Recommendations for the States." *Capital Ideas* TC 88.02 (15 June 1988).

Establishes the results of the National Governors' Association work directed toward standardizing the reporting of truck crashes. This issue contains the rationale, fields to be used, and codes for those fields.

Viner, John G. "Harmful Events in Crashes." *Accident Analysis and Prevention* 25, no. 2 (1993) 139–145.

The study examined objects struck in motor vehicle crashes which cause injury or property damage, called harmful events on national accident data files. Both first, and most, harmful events were analyzed and shown to have significantly different attributes. This indicates the need for both to be reported on police crash forms. First harmful events are useful for crash mitigation, while most harmful events are useful for severity mitigation.

Viner, John G. "The Roadside Safety Problem." *Transportation Research Circular 435.* 17–29. Washington, DC: Transportation Research Board, January 1995a.

To obtain a good view of the nature of the roadside problem, all types of crashes need to be examined. Suggests that comprehensive crash costs is one method to present a rational way of examining problem. Any roadside safety improvement should be directed toward reducing crash losses. Author proceeds to examine various types of crashes using data obtained from various federal databases. Also examines emerging trends in vehicles and roadside elements which

may ultimately help reduce the effect of the roadway on crash losses.

Viner, John G. "Rollovers on Side Slopes and Ditches." *Accident Analysis and Prevention* 27, no. 4 (1995b) 483–491.

National data were analyzed to define the nature and importance of the problem of ran-off-the-road vehicles that roll over on slopes and ditches. Also, data from two specialized databases were used to obtain insight on vehicle orientation and driver maneuvers in such crashes. The crash type was found to be the leading cause of ran-off-road driver fatalities, accounting for about one-fourth of this total. Highway factors associated with this crash type are identified to assist in the effort to define specific roadway locations where highway design countermeasures may be appropriate. Specifically, attention should be given to the outside of horizontal curves on rural two-lane roads. Vehicle dynamics computer simulations appear to offer the most promising approach to obtain needed insight on rollover risks for specific slope and ditch geometric combinations. Vehicle trajectory information found in this study should be useful in the design and interpretation of needed follow-on simulation studies. Vehicle trajectories in slope rollovers were found to be both different from, and more complex than, fixed object crashes.

Waard, Dick de, and Ton Rooijers. "An Experimental Study to Evaluate the Effectiveness of Different Methods and Intensities of Law Enforcement on Driving Speed on Motorways." *Accident Analysis and Review* 26, no. 6 (December 1994) 751–765.

Two field experiments were conducted to establish the most effective method of enforcement in reducing driving speed and to establish the most efficient strategy in terms of police force personnel required. In the first experiment, the effect of three variables on driving speed on motorways was studied. The first variable, intensity of enforcement, was manipulated by creating three different objective levels of apprehension for detecting speeding drivers. The second variable was method of enforcement. On-view stopping and ticketing of offenders was compared to mailing of fines on the basis of the car's license plate number. The third variable manipulated was the time delay in the mailing of fines. Time delay between detection of the offense and feedback to the driver was shortened in one condition. In a second experiment, police enforcement effort was optimized by relating intensity level of enforcement to the proportion of speeding vehicles. In the first experiment, police enforcement was applied for four weeks; in the second experiment, enforcement activities were continued for 12 consecutive weeks. In both cases the main dependent variable was driving speed. Before, during, and after the application of enforcement, speed was registered using induction loops. In addition, driver opinion about speeding and speed enforcement was studied using postal questionnaire surveys. The results show the largest and longest lasting reduction in driving speed in the highest intensity level condition, giving support for a relation between objective chance of apprehension and speed choice. On-view stopping of offenders was shown to be a more effective method to reduce driving speed than mailing of fines. Some of these results are discussed in the light of game theory. The questionnaire surveys indicated that most drivers did not notice the recurrence in enforcement activities due to infrequent passing of the sections of motorways studied. The preventive effect of police enforcement appeared to be far more substantial than its repressive effect. Enforcement primarily deters the current nonoffender from speeding.

Wackrill, P. "A Design Tool to Identify Those Elements of a Road Network Necessary to Support an Efficient Traffic Routing Pattern." *Mathematics in Transport Planning and Control (Proceedings)*. 231–239. Oxford, England: Clarendon Press, 1992.

In an urban road network, with its relative density of junctions, it is the competition for road space at junctions that is a major contributor to both delay and the potential for accidents. One method of reducing that competition would be to allocate a route to each driver which involves minimum conflict with the other streams of traffic using each junction. We show that repeated application of this principle to each driver in turn results in a relatively efficient routing pattern. A suite of computer programs, for use on a microcomputer, has been developed as a design tool to find such a routing pattern for a given road network and trip matrix. With this design tool a traffic engineer could explore the potential for allocating trips more efficiently. He would be interested in those links most used by such an efficient allocation. Some links will only be used in one direction; these would be suitable candidates for one-way operation. Reduction in conflict at junctions will sometimes be achieved by the complete avoidance of certain turning movements; these turns could be banned. Some properties of routing patterns found for one real and one idealized network are described in the paper.

Wallen, Martin A. "What Makes a Good Safety Management System?" *ITE Journal* (January 1993) 26–30.

Traffic engineering long has been assumed to use traffic safety information and to correct whatever problems are considered engineering related. However, the two are not equivalent. Human factors and road user needs are important components normally not included in traffic engineering education; yet, they play an important role in design. Need to clearly understand the use of highway standards. Strict adherence to the dogma can produce undesirable results. In some cases, courts have found engineers liable for holding to standards which were at odds with either how drivers behaved or perceptions of the road user. Improvements in design need to arise both from engineering principles and from an organizational perspective which views the driver and vehicle as key components. The use of the Safety Management

System specified in ISTEA helps provide appropriate data from which to develop information useful for generating appropriate engineering changes. The Institute of Highways and Transportation in London, England has developed a 'safety audit.' The purpose is to examine inadequacies in design and standards through close examination of the safety aspects and then to inaugurate changes in new design. Increasingly the Institute is also beginning to apply the audit to rehabilitating older roads. Additionally, the engineer must move from 'spot' improvements to considering improvements over multiple segments, in a corridor, or in neighborhoods. Need to mate adequate safety databases with GIS and with CADD software to help with preparing collision diagrams. A good SMS will strive for reduction in crashes as a goal, not just reaction to a goal.

Wasill, Richard G. "Accident Analysis as a Decision Tool in Rehabilitating Park Roads." *Parkways Conference Proceedings, Linear Parks Conference.* 230–237. Boone, NC: Appalachian Consortium Press, 1987.

In 1986, the Western Direct Federal Division (WDFD of FHWA) was requested by the National Park Service (NPS) to design and construct an 18-mi resurfacing project in Mt. Rainier National Park from the Nisqually entrance to the Paradise visitors complex. This project was programmed for minor widening to attain a uniform 24-ft width, to make minor drainage corrections, and to make several spot safety improvements along the route under a RRR concept. The design procedures require the identification of any exceptions to full standards which, in this case, consist of the NPS Park Road Standards adopted in 1984. The park road standards for this route warrant a 35 mph design speed with a 28-foot paved top width for the estimated 1,700 ADT. The maximum regulatory speed is posted at 35 mph. By way of comparison, AASHTO Recreational Road Standards would require a roadway width of 26 to 32 ft. Due to the substantial number of exceptions and potential for associated risks, a comprehensive accident analysis was performed on an interagency basis to ensure that the proposed work properly addressed areas which safety enhancement should incorporate into the project. This paper provides a brief summary of that comprehensive report dated August 1986.

Wolf, Theodore A. *Survey of States for Existence of Large-Truck Accident Rates and Computerized Databases that Could Be Analyzed to Obtain Large Truck Accidents.* Albuquerque, NM: Sandia National Laboratories, March 1989.

Reviews the crash data for large trucks found in state crash files. Report noted that while much information is available, it cannot be combined with that from other states. Primary problems include inadequate definitions of commercial vehicles, fields of data collected, and codes used. Need to aggregate data in order to study potential contribution of roadway to truck crashes. This study may have served to justify the NGA study and subsequent introduction of standardized data collection for commercial vehicles.

Woodham, David B. *In-Service Evaluation of Highway Safety Appurtenances: FHWA Experimental Project #7.* DTP-R-88-7. Denver, CO: Colorado Department of Highways, March 1988.

Studied performance of guardrails and end treatments based on actual crash experience. Included a cost-effectiveness analysis. (See also James A. Mohamed, same title, November 1990, DTD-R-90-13.)

Wright, C. C., C. R. Abbess, and D. F. Jarrett. "Estimating the Regression-to-Mean Effect Associated with Road Accident Black Spot Treatment: Towards a More Realistic Approach." *Accident Analysis and Prevention* 20, no. 3 (June 1988) 199–214.

Until recently, the evaluation of engineering remedial measures at road accident black spots was seen as a routine exercise. However, the regression-to-mean effect has been found to distort comparisons between before-and-after accident data to a significant extent, and for this and other reasons the problem can no longer be considered as straightforward. Various methods for applying corrections for regression-to-mean have been proposed. They rely on various assumptions about the data which have not been properly investigated or justified. These assumptions relate to the nature of the distribution of mean accident rates between sites, the nature of the population from which the sites are drawn, and the validity of using total accident frequencies as evaluation criteria. The aim of the paper is to investigate the validity of the assumptions, to assess the robustness of the results which are based on them, and to put forward some suggestions for improving the quality of the results.

Wu, Chong Qing. "Uniformity of Highway Safety Data in the United States." Master's Thesis. Evanston, IL: Northwestern University, June 1994.

Wu, Chen-Chin, and Ramey O. Rogness. "Passing Lane Feasibility for Ohio's Two-Lane, Two-Way State Rural Highways." Paper #950591 presented at the Transportation Research Board, Washington, DC, 22 January 1995.

Highway statistics show that Ohio two-way two-lane rural highways constitute 48 percent of all the roadway mileage. Passing lanes have proved to be beneficial in reducing accident rate and delay on such highways. However, for Ohio, passing lanes have not been considered or utilized. This research focuses on a passing lane analysis to evaluate the practicality of passing lane installations and tries to develop some criteria for consideration of the use of passing lanes on the Ohio two-lane rural road system. A microscopic simulation program entitled 'TWOPAS' was used to investigate selection of road sections. The objective of this study is to select and identify those road sections where passing lanes could improve safety and operational problems and to determine the appropriateness of the proposed passing lane design for operational improvements. Three sites are chosen using a

selection criteria for detailed study. All sites had a number of intersections located within their segments. For each site, Type A and Type B passing lane configurations were considered along with their location within each segment. The location was based on the present year and 2008 year Level of Service (LOS) and percent time delay as MOEs. Based on the simulation results, a passing lane was determined to be feasible and improved the LOS at all sites. Site 1 was where a passing lane would be effective. The study showed the feasibility and application of passing lanes for Ohio's rural two-way two-lane state highways. Recommendations based on this study are (1) TWOPAS simulation program should consider intersection turning effects, provide an improved data input routine, and increase the number of grade points allowed and (2) the Ohio Department of Transportation needs to improve its data resources so that more similar studies can be undertaken in the future.

Young, Peter. "Report into the Use of Geographic Information System Software for the Capture of Traffic Accident Location Data." *Proceedings, 16th Conference.* Perth, Australia: Australian Road Research Board, November 1992.

Following a review of the method by the NSW Roads and Traffic Authority to capture traffic accident location data, a pilot project to research the feasibility of using GIS software to assist in the task was undertaken. This involved the design and development of an application on a PC platform and subsequent capture of 2,000 accident records. The project revealed that the GIS-based process was superior in terms of integrity of data captured, extent of data captured, and that it also offered considerable gains in terms of efficiency in the coding process and in maintenance of the system. The success of the project has resulted in the inclusion of a GIS-based location capture function in the RTA's new accident recording system, to have been implemented in early 1993. The application is relevant to any organization involved in the capture and/or analysis of spatially located incident information, and highlights the benefits of user friendly GIS interfaces.

Zador, Paul *et al.* "Relationships Between Vertical and Horizontal Roadway Alignments and the Incidence of Fatal Rollover Crashes in New Mexico and Georgia." *Transport Road Research Laboratory 1111.* 27–42. Berkshire, Great Britain: Transport Road Research Laboratory, 1987.

Survey data on curvature and grade, collected at the sites of single-vehicle rollover crashes and at random comparison sites in New York and Georgia were analyzed to determine the relationship of horizontal and vertical alignment to such crashes. The geometric data were not readily available from archival sources.

Zegeer, Charles V., R. Stewart, F. Council, and T. R. Neuman. "Accident Relationships of Roadway Width on Low-Volume Roads." *Transportation Research Record 1445.* 160–168. Washington, DC: Transportation Research Board, 1994.

An analysis was performed to quantify the accident effects of lane and shoulder widths on rural roads carrying fewer than 2,000 vehicles per day. The primary database used in the research contained accident and roadway characteristic information for more than 6,600 km (4,100 mi) of two-lane roadway sections in seven states. Independent databases from three states (Minnesota, Illinois, and North Carolina) for roadways totaling more then 86,000 km (54,000 mi) were selected to validate the accident relationships found in the primary database. Analysis of covariance was used to quantify accident relationships on these low-volume roads. Single-vehicle and opposite-direction accidents were classified as related accidents because the accident rates for these two types were found to be related to differences in lane and shoulder widths. The rate of related accidents was also affected by roadside hazard, roadway terrain, the number of driveways per mile, and state differences. No differences in accident rates were found between roadways with paved and unpaved shoulders. For lane widths of at least 3.0 m (10 ft), related accident rates were lower when side shoulders were present than when narrow shoulders were present. For a given shoulder width, wider lanes were found to be associated with lower accident rates. Somewhat counterintuitively, the accident rate was higher for 3.0-m (10-ft) lanes with narrow shoulders than for 2.7-m (9-ft) lanes with narrow or wide shoulders. For traffic volumes of 250 vehicles per day or less, accident rates did not differ significantly between paved and unpaved roads. For traffic volumes of greater than 250 vehicles per day, paved roads have significantly lower accident rates than unpaved (dirt and gravel) roads. The research findings indicate that on low-volume roads, lane widths as narrow as 2.7 m (9 ft) may be acceptable from a safety standpoint under certain conditions. The 1995 draft AASHTO policy chapter on local roads includes revised roadway width guidelines that reflect many of the research findings presented.

Zegeer, Charles V. *et al. Safety Effectiveness of Highway Design Features; Volume II: Alignment.* RD 91-045. Washington, DC: Federal Highway Administration, November 1992a.

Through review of recent literature, this study focused on vertical and horizontal alignment, along with roadway cross-section. Findings show that vertical downslope has significant effects on crash rates. Sixty-three percent more crashes on downslopes than upslopes. Horizontal alignment more difficult to quantify, therefore need to measure relationships. Includes sight distances, roadside hazards, pavement friction, traffic control devices, etc. Model to estimate likelihood of high hazard sites needs to combine length and degree of curvature along with roadside and pavement ratings. Shoulder width also important. With model, however, can estimate contribution of individual components. Spiral transitions found to reduce crashes; so does superelevation. General findings are

that sharp curvature to the left or downgrade frequently associated with crashes, particularly those resulting in injury. Studies have generally overlooked improvements in drainage as part of addressing cross section. Literature referenced through 1991.

Zegeer, Charles V. *et al. Safety Effects of Cross Section Design for Two-Lane Roads.* RD 87/008-009. Washington, DC: Federal Highway Administration, October 1987.

Zegeer, Charles V., Jane C. Stutts, and William W. Hunter. *Safety Effectiveness of Highway Design Features; Volume VI: Pedestrians and Bicycles.* RD 91-049. Washington, DC: Federal Highway Administration, November 1992b.

Summarizes pedestrian and bicycle research related to characteristics and types of crashes, and countermeasures employed to reduce the crashes. Relationships to geometric features also included with emphasis on sidewalks, grade separated crossings, refuge islands, malls, neighborhood traffic control, and improved shoulders. In terms of bicycles, also discusses facilities for bicycle travel, including design and performance. Literature referenced through 1991.

Zegeer, Charles, and Forrest M. Council. *Safety Effectiveness of Highway Design Features; Volume III: Cross Sections.* RD 91-046. Washington, DC: Federal Highway Administration, November 1992.

Past studies have revealed that more than 50 roadside features have been related to vehicle crashes. In summary, lane and shoulder width and type have been most predominate in their relationship. Little research has been done where control has been made for roadside clear zone; therefore, the land and shoulder cannot be considered as a sole element. Generalized review shows overall direct relationship between road and shoulder widening and decrease in crashes. Paving shoulders also has resulted in crash decreases. However, these actions also take place along with widening of roadside clear zone, adding confounding effects. Sideslope ratio increases result in fewer rollover crashes, particularly with trucks. For specific obstacles, crashes are most likely to occur with utility poles. Bridges and overpasses are the largest contributors to fatal crashes. Trees and culvert head walls are second in fatality-producing crashes. Studies also referenced include narrow bridges and differing roadway medians on multilane roads. Literature referenced through 1991.

Zhou, Hiping, and Robert D. Layton. "Development of Prototype Expert System for Roadside Safety." *Journal of Transportation Engineering* 117, no. 4 (July 1991) 435–456.

Collision of vehicles with fixed objects adjacent to the roadway has been a concern of traffic engineers for many years. One solution to prevent or reduce the number of accidents of this type is to install a traffic barrier to shield the objects from being hit directly. However, because the barrier itself is a fixed object, the question is whether a barrier is more effective at a particular location than no barrier at all. If a barrier is needed, where should it be located and what type of barrier would satisfy the design criteria? Issues of this nature are ill-structured and difficult to address using normal computing technology since many factors contribute to the problem. For roadside safety, the primary factors are diverse and interrelated. This paper presents a demonstration prototype knowledge-based expert system (Roadside) for roadside-safety analysis. In particular, this system is developed to evaluate whether a traffic barrier is necessary for a particular site in analysis. Development of this demonstration prototype shows that an expert-system approach for roadside safety analysis is feasible. The artificial-intelligence (AI) programming language Prolog is used for developing the system. The use of Prolog provides greater flexibility and adaptability in developing the system. However, much more programming time is required to develop the expert system.

APPENDIX C

CONTACT SURVEY AND RESPONSES

A brief survey, provided at the end of this appendix, was sent to the Governor's Highway Safety Representative of each state on April 19, 1995. A reminder letter was sent May 26 to those not yet responding. The primary objective of the survey was to obtain names and numbers for further contact on details, as work proceeded on the project. However, the opportunity was taken to ask a few, very general, questions to provide an update on the team's perspective regrading state practices. Thirty-three states responded as of the end of July 1995. A copy of the survey follows this narrative. The responses were coded and a relational database created to support analysis and use of the information.

Twenty four of the respondents provided a current copy of their PCRs. Five states indicated that they were in the process of making significant revisions to the form that was submitted.

The first question was directed at gaining a general idea of the extent to which three national standards—ANSI, NGA, and CADRE—were being used. The responses are summarized in Table C-1. The particular ANSI standard was not specified, because the objective was not to complicate the survey but to get general perspectives. Very few states indicated complete adoption of these standards. Roughly an equal number indicated either partial adoption or none. The relatively large number of states indicating no compliance, even though these are not newly published standards, was unexpected. Further review of the specific crash reports, especially with regard to items potentially of interest for highway design, may be appropriate.

One or two respondents noted that although they used common data elements, the codes varied from those recommended in the standards. Several of the respondents commented that they were looking at improving compliance with the standards. Respondent comments suggested that a driving force for this were the system management standards (SMS) requirements of ISTEA. One state indicated that they were unfamiliar with CADRE and NGA standards.

One third of the 33 states responding indicated that they were not able to link their roadway inventory data with PCR files; the rest indicated that this was possible, but some qualified that capability. Some states have linkages for only a limited number of roadway classes. One state indicated that, although such a linkage was technically feasible, it was not allowed for other reasons. Other states indicated that although linkage was not currently possible, they were experimenting with creating this capability. Again, the comments suggested that the primary motivation was SMS requirements.

Table C-2 provides a summary of the responses on use or testing of technologies to improve safety data. Computer-based tools are being widely used, but not as widely as expected.

The mode of the frequency for the number of technologies indicated by a state was three. It was surprising that 17 states indicated use of an instrumented vehicle for collecting roadway inventory.

In general, the "other" choice was used by respondents to make further comments, rather than to indicate other technologies in use or under testing. One state indicated that they were using automated forms-generating software which, presumably, other states may have included under the "personal computer" choice.

TABLE C-1 Reported Compliance with National Standards

Level of Compliance	Source of Standard		
	ANSI	CADRE	NGA
Completely	4	4	9
Partial	14	14	12
Not at All	13	14	11
No Response	2	1	1

33 states responded to the survey

TABLE C-2 Reported Use or Testing of Technologies for Data Collection

Type of Technology	Number of States Indicating Use or Testing
Portable Computers	18
Global Positioning Systems (GPS)	16
Instrumented Vehicle for Inventory	17
Geographic Information System (GIS)	19
GIS and Image Recognition from Videologs	9
Bar Code, Mag. Stripe, or Smart Cards	8
Laser-based Measurement	9
Other	5
No Items Selected	2

33 states responded to the survey

TABLE C-3 Reported Use or Testing of Technologies for Data Management

Type of Technology	Number of States Using or Testing
Scannable Forms (OCR or OMR)	10
Relational, Object-Oriented or Distributed Data Bases	10
Aerial Imaging of Roadways	5
Other	4
No Items Selected	3

33 states responded to the survey

TABLE C-4 Technologies Reported to be Used or Tested for Facilitating Use of Safety Data

Type of Technology	Number of States Indicating Use or Testing
Linkage Between Crash Reports and Medical Data	12
Geographic Information Systems	15
Direct End-User Access Using Graphical Interfaces	8
Data Analysis or Modeling Tools	11
Decision-Support Systems	10
Other	2
No Items Selected	1

33 states responded to the survey

States appear less involved in using or experimenting with new technologies for data management than for data collection. Table C-3 summarizes results from this part of the survey. The use of scannable forms seems to be increasing rapidly, but the upgrading of outdated database management systems seems to be lagging. The use or testing of aerial imaging was more prevalent than expected and should be further explored in direct contacts. In addition to further explanatory comments, the "other" choice included a reminder that scannable forms can be implemented as part of a document imaging system.

TABLE C-5 Number and Type of Contacts Provided

Type of Contact	Number
County Agency Design User	20
Data Collection	29
Data Management	27
Police Crash Report Design	32
Regional Agency Design User	18
Roadway Inventory	31
State Agency Design User	31
Urban Agency Design User	30
Total	218

33 states responded to the survey

States are only starting to address the application of technologies to facilitate the use of safety data. Table C-4 summarizes the responses to the survey. Less than 40 percent of the respondents indicated use or testing of GIS. However, a third of the respondents indicated that they were working on linkage with medical data sources. Although there were only eight states using graphical interfaces for end users, it was at a greater frequency than expected and at an area to detail in further direct contacts.

Table C-5 provides a sense of the success of the survey at accomplishing its primary goal of identifying persons for further contacts. A total of 218 contact-types was identified. Some of the contact types may be the same person at a given state. This range and depth of persons will allow ready access to current practices, ideas and reactions as work proceeds. These names have been entered into the survey database for quick retrieval.

APPENDIX D

DATA DICTIONARY

The data dictionary provides an overview of the safety, geometric, and traffic-related data elements essential to a system designed to support highway safety design decisions. Many of the elements either are not currently collected and maintained, or the level of detail or accuracy is insufficient to adequately serve traffic safety analyses.

Although all of the elements are considered important, some are viewed as particularly critical, including data from *traffic crashes, traffic operations data,* certain elements of *geometric design data,* and *traffic control data.* The following is an overview of the particularly critical data elements.

TRAFFIC CRASHES

Highway engineers have long depended on traffic crash reporting to help provide information about dangerous locations. Summary statistics have formed the basis for HHL analysis and crash diagramming. The reports have been used to examine individual crashes more fully for events and contributory factors. However, traffic safety personnel also have recognized the many quality issues surrounding the collection and recording of data, especially for such elements as location, manner of collision, contributory factors, and sequence of events. Nationally, much effort has gone into designing standardized approaches both through the CADRE and ANSI standards and, more recently, through the work on CODES, where injury data from hospital records is matched to crashes causing those injuries.

Unfortunately, a growing trend, especially in metropolitan areas, is for police to investigate fewer and fewer crashes. They report what was told to them by motorists and add any observations they make on scene. Some police agencies now are going one step further. Persons involved in minor (non injury-producing) crashes are directed to report to the nearest police station to make a report. This report then reflects the limited, and probably biased, information that the involved driver is willing to provide. One of the key losses in this process is data about the location of the crash (some police believe themselves fortunate to even get the correct municipality name). Given the increased pressures placed on police to perform law enforcement services and the failure of budgets to maintain a "desired" level of policing, the managers are cutting out what they perceive as unnecessary work. Crash reporting is seen in this category.

TRAFFIC OPERATIONS DATA

Traffic volume is the single most important variable contributing to the frequency of crashes. Particularly critical data include intersection turning movements and vehicle classification data. Such data are usually either not maintained or counted at insufficient locations to be useful for systemwide safety information needs. With the advent of widespread computerized traffic signal system networks that collect and process traffic volume data for operations, such data should be available for use in the safety system. All that is necessary is the establishment of linkages, enabling capture of this database.

Other safety-related operations data that are critical include measures of speed. Such data are not generally collected and maintained, but would be essential to designers.

GEOMETRIC DESIGN DATA

There are many geometric elements currently lacking in availability and/or quality of data. Those that are the most critical include descriptions of the roadside, vertical alignment, and intersections.

Roadside data are generally not maintained. Slope, clear zone, type of obstacles and their location are included. Also of importance is information on the location, design, and characteristics of roadside barriers. In the future, with the use of GIS databases and more sophisticated automated vehicle inventorying systems, capture and maintenance of roadside data should be viable and cost-effective. Also, automatic input of CADD design data, as well as maintenance records involving crash cushion repair, guardrail repair, etc., would greatly enhance understanding and design of the roadside.

Intersections are among the most important features affecting safety. Currently, little information is available for designers other than location. Items of importance that should be maintained in a safety-sensitive database include the traffic control, presence of channelization, intersection sight distance, and traffic volume/movement through the intersection.

With respect to alignment, both horizontal and vertical alignment, horizontal data are generally available and more readily obtainable. Vertical alignment and, in particular, the resultant stopping sight distance and passing sight distance information are for the most part not available under current data systems. Input of CADD data, the use of IHSDM to generate sight distance profiles for input to databases, and

automated vehicle inventory systems in the future should provide the means to obtain these data.

TRAFFIC CONTROL DATA

Critical safety information that should be available includes traffic control, which includes signing, pavement marking, signal systems, regulations, etc. Such information should be maintained for presence, adherence to prevailing criteria, and condition/reflectivity, etc.

In the future, automated vehicle inventory systems and GIS-based sign inventories linked to the geometric data will provide more complete, integrated data for designers.

DESCRIPTION OF THE TABLE

The data dictionary (Table D-1) is divided into two major sections, crash characteristics (from the crash report) and roadway characteristics (most of which come from the roadway inventory, but include other topics such as traffic counts, administration, and comments and complaints). Each of the two major sections are divided into various subsections.

For each entry on the table, five primary characteristics are provided. Within the major characteristics are secondary ones. These are defined below:

1. Element - the name commonly given to the element of data collected.
2. Description - a brief description of the element.
3. Safety-Related Requirements:
   a. Dimension - the type of data collected and accuracy that should be expected.
   b. Collection Frequency - how often data need to be collected for this element. All crash report data are collected once and are mainly from the crash report. However, similar elements may be collected elsewhere either originally or duplicated (the more usual example), such as from insurance reports or supplemental police reports.
4. Current Collection - The current aspects of data collection:
   a. Quality - the relative quality of the data, a combination of quality attributes, but most specifically coverage, accuracy, and consistency of reporting.
   b. Sources - the primary source of the data and secondary sources, if any.
   c. Technologies - the technologies that either are used to assist with data collection or could be used currently.
5. Future - how the process might evolve in the future; an assumption is made that the process will improve quality wherever it is not already high and it will reduce time required.
   a. Sources - the revised sources of the data.
   b. Technologies used - the technologies that can be employed and may represent those already employed.

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Crash Report								
Crash - General								
Date	mm/dd/yy	Day of week	Once[1]	High	PCR/Computer -Aided Dispatch (CAD)	Computer clock	Computer generated report	Computer Clock
Time	hh:mm	±15 minutes	""	High	PCR/Computer -Aided Dispatch (CAD)	Computer clock	Computer generated report	Computer Clock
Location[2]	Location of the crash referenced to an address, offset, milepost, etc.	±10 m	""	Medium	PCR	(limited) GPS	GPS Interface	GPS with ±1m accuracy
Manner of collision	How the vehicles collided, e.g. front to rear, or how a pedestrian/ bicyclist were involved, e.g. bicyclist ran into automobile side.	Categorical[3]	""	Medium	PCR/Insurance reports	None	Insurance report summary/RF ID Chip	RF ID chip receiver
Road surface condition	Condition of the surface at the time of the crash, e.g. wet or dry.	Categorical	""	Medium	PCR	None	Central traffic control	Surface condition detectors
Light condition	Ambient light at the time of collision, including the presence or absence of night-time illumination.	Categorical	""	Medium	PCR	None	Light meter on vehicle	Electronic Light meter
Traffic control device condition	Condition of traffic control device where the device may have been contributory to the crash.	Categorical	""	Medium	PCR/Maintenance records	None	Feed to central traffic control	Linked signals
Weather	Weather conditions at time	Categorical	""	Medium	PCR	None	Computer generated report	None
Killed	Number of persons killed in the crash.	Number	""	High	PCR/Hospital records/FARS[4]	None	Linked trauma records persons killed in the crash.	None
Injured	Number of persons injured in the crash.	Number	""	Medium	PCR/Hospital records	None	Linked trauma records	None

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
- by Vehicle								
VIN	Vehicle Identification Number	17-digit number	Once	Medium	PCR/DMV[5]	Bar code	Bar code; RF chip	Bar code reader; RF ID system
Killed	Number of persons killed in the vehicle.	Number	""	High	PCR/Hospital records/FARS	None	Linked trauma records	None
Severity of injuries	Severity of the injuries to persons, generally the most severe injury.[6]	Number by severity	""	Medium	PCR/Hospital records	None	Linked trauma records	None
Vehicle damage	The degree and location on vehicle of damage.	Location on vehicle and extent	""	Low	PCR	Photogrammetry	Videotape; Pictures	Automated photo or video interpretation; Photogrammetry
Direction prior to crash	The direction the driver was traveling on the roadway prior to the crash.	Direction relative to roadway	""	High	PCR/Supplemental interviews	None	RF ID chip	RF chip receiver
Intended maneuver	The maneuver the driver attempted to make prior to the crash, e.g. turn left.	Categorical	""	Low	PCR/Supplemental interviews	None	Computer generated report	None
Actual maneuver	The maneuver actually made prior to the first harmful event.	Categorical	""	Medium	PCR/Supplemental interviews	None	RF ID chip	RF chip receiver
First harmful event[7]	The event which precipitated the crash and which resulted in some harm, e.g. struck guardrail.	Categorical	""	Low	PCR/Subsequent investigation[8]	None	RF ID chip	RF chip receiver
Location, first harmful event	The location where the first harmful event occurred.	±10 m	""	Low	PCR/Subsequent investigation	GPS location	GPS receiver	GPS with error correction
Location, first harmful event relative to road	The location where the first harmful event occurred as it related to the roadway, e.g. struck a signpost on the right shoulder.	Categorical	""	Medium	PCR/Subsequent investigation	GPS location	GPS receiver linked with CADD system	GPS with error correction

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Most harmful event	What occurred that caused the most damage and injury.	Categorical	""	Medium	PCR/Subsequent investigation	None	RF ID chip	RF ID chip receiver
Location, most harmful event	The location where the most harmful event occurred.	±10 m	""	Low	PCR/Subsequent investigation	GPS location	GPS receiver	GPS with error correction
Location, most harmful event relative to road	The location where the most harmful event occurred relative to the roadway, e.g. collided with another vehicle in the center of the intersection.	Categorical	Once	Medium	PCR/Subsequent investigation	None	GPS receiver linked with CADD system	GPS with error correction
Driver condition	The condition of the driver, both physical and physiological.	Categorical	""	Low	PCR/EMS statements	None	Computer generated report/Field sobriety test	Drug/alcohol portable testing devices
- Contributing Circumstances								
Pedestrian or bicyclist	How the pedestrian or bicyclist contributed to the crash.	Categorical	Once	Medium	PCR/subsequent investigation	None	Computer generated report	None
Driver	Actions taken by the driver that contributed to the crash.	Categorical	""	medium	PCR/Subsequent investigation	None	Computer generated report	None
Environment	How the environment contributed to the crash.	Categorical	""	Medium high	PCR/Subsequent investigation	None	Computer generated report	None
Highway	How the roadway contributed to the crash.	Categorical	""	Medium	PCR/Subsequent investigation	None	Computer generated report	None
Other	Any other elements which may have contributed to the crash, e.g. a deer or piece of debris on the roadway.	Categorical	Manual	Medium high	PCR/Subsequent investigation	None	Computer generated report	None

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Roadway Characteristics (Inventory)								
Cross Section - Lanes								
Number	Number of lanes on section.	Categorical	When changed or newly constructed	High	Roadway inventory/Plans	Photolog (Videolog); Coding of Data from Plan Sets	Automatic Plan updates with periodic field inventory	CADD files; Automated Vehicle Inventory Systems (AVIS); Satellite/Aerial Surveillance
Movements	Type of lane/movement, e.g. left turn lane, ramp, one-way, etc.	Categorical	""	High	Roadway inventory/Plans	Photolog (Videolog); Coding of Data from Plan Sets	Automatic Plan updates with periodic field inventory	CADD files; AVIS; Satellite/Aerial Surveillance
Length	Length of the lane for the section being identified.	±1 m	When changed or newly constructed	High	Roadway inventory/Plans	Photolog (Videolog); Coding of Data from Plan Sets	Automatic Plan updates with periodic field inventory	CADD files; AVIS; Satellite/Aerial Surveillance
Width	Width of lane.	±0.1 m	""	Medium high	Roadway inventory/Plans	Photolog (Videolog); Coding of Data from Plan Sets	Automatic Plan updates with periodic field inventory	CADD files; AVIS; Satellite/Aerial Surveillance
Cross slope	Percent of slope.	±0.5%	""	Low	Roadway inventory/Plans	Generally not maintained in inventories	Automatic Plan updates with periodic field inventory	CADD files; Automated Vehicle Inventory Systems
- Median								
Type	Type of median, (e.g. raised, flush, barrier, none).	Categorical	When changed or newly constructed	High	Roadway inventory/Plans	Photolog (Videolog); Coding from Data Plan Sets	Automatic Plan updates with periodic field inventory	CADD files; AVIS; Satellite/Aerial Surveillance

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Width	Width of median or barrier, if applicable	±0.1 m	""	High	Roadway inventory/Plans	Photolog (Videolog); Coding from Data Plan Sets	Automatic Plan updates with periodic field inventory	CADD files; AVIS; Satellite/Aerial Surveillance
- Shoulder and Roadside								
Shoulder								
Type	Paved, Stabilized, Turf, Combination, None	Categorical	When changed or newly constructed	High	Roadway inventory/Plans/ Pavement Management System (PMS)	Photolog (Videolog); Automated Vehicle Systems for PMS; coding of Data from Plan Sets	Automatic Plan updates with periodic field inventory	CADD files; Automated Vehicle Inventory Systems
Width	Width of Shoulder	±0.1 m	""	High	Roadway inventory /Plans/ PMS	Photolog (Videolog); Automated Vehicle Systems for PMS; Coding of Data from Plan Sets	Automatic Plan updates with periodic field inventory	CADD files; AVIS; Satellite/Aerial Surveillance
Cross slope	Cross slope of shoulder in percent	±0.5%	""	Low	Roadway inventory /Plans/ PMS Generally not maintained	Generally Not Maintained: Coding of Data from Plan Sets	Automatic Plan updates with periodic field inventory	CADD files; Automated Vehicle Inventory Systems
Curb								
Type	Type of curb (Barrier, mountable, none)	Categorical	When changed or newly constructed	Low to Median	Roadway inventory/Plans often not maintained	Coding of Data from Plan Sets	Automatic Plan updates with periodic field inventory	CADD files; Automated Vehicle Inventory Systems

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Height	height of curb	±1 cm	""	Low	Roadway inventory/Plans often not maintained	Coding of Data from Plan Sets	Automatic Plan updates with periodic field inventory	CADD files; Automated Vehicle Inventory Systems
Barrier, by side								
Type	Type of barrier used or guardrail	Categorical	When changed or newly constructed	Low - data not generally maintained	Roadway inventory/Plans; maintenance records	Photolog (Videolog); Coding of Data from Plan Sets	As-designed or as-built plans; computerized maintenance files; periodic field inventory	CADD files; Automated Vehicle Inventory Systems; Satellite/Aerial Surveillance
Length	Length of barrier or guardrail by reference to start end stations	±0.5 m	""	""	Roadway inventory/Plans; maintenance records	Photolog (Videolog); Coding of Data from Plan Sets	As-designed or as-built plans; computerized maintenance files; periodic field inventory	CADD files; AVIS; Satellite/Aerial Surveillance
End treatment	Type of treatment of the end	Categorical	""	""	Roadway inventory/Plans; maintenance records	Photolog (Videolog); Coding of Data from Plan Sets	As-designed or as-built plans; computerized maintenance files; periodic field inventory	CADD files; Automated Vehicle Inventory Systems
Height	Height of barrier or guardrail	±0.05 cm	""	""	Roadway inventory/Plans; maintenance records	Photolog (Videolog); Coding of Data from Plan Sets	As-designed or as-built plans; computerized maintenance files; periodic field inventory	CADD files; Automated Vehicle Inventory Systems

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Offset from travel lane	Offset of barrier or guardrail from travel lane	±0.5 m	""	""	Roadway inventory/Plans; maintenance records	Photolog (Videolog); Coding of Data from Plan Sets	As-designed or as-built plans; computerized maintenance files; periodic field inventory	CADD files; Automated Vehicle Inventory Systems
Appurtenances								
Type	Type of appurtenance (Light pole, sign, utility pole)	Categorical	When changed or newly constructed; periodic inventory (1 to 5 years)	Medium	Roadway inventory /Sign inventory Not all appurtenances generally maintained	Photolog (Videolog); Coding of Data from Plan Sets	As-designed plans and automated Vehicle Videolog; GIS-based utility and sign inventories	Automated Vehicle Inventory Systems; CADD files; GPS for field work
Location - horizontal[9]	Distance offset from reference point (or x, y coordinates).	±1 m	""	Medium to low	Roadway inventory /Sign inventory Not all appurtenances generally maintained	Photolog (Videolog); Coding of Data from Plan Sets	As-designed plans and automated Vehicle Videolog; GIS-based utility and sign inventories	Automated Vehicle Inventory Systems; CADD files; GPS for field work
Location - offset	Distance offset from the center line or edge of pavement.	±0.1 m	""	Medium to low	Roadway inventory /Sign inventory; Not all appurtenances generally maintained	Photolog (Videolog); Coding of Data from Plan Sets	As-designed plans and automated Vehicle Videolog; GIS-based utility and sign inventories	Automated Vehicle Inventory Systems; CADD files; GPS for field work

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Side Slope								
Clear Zone	Distance offset from edge of pavement to obstruction or ditch	±0.1 m	When changed or newly constructed; periodic inventory	Low - generally not maintained	Roadway inventory (Generally not maintained)	Photolog (Videolog); Coding of Data from Plan Sets	As-designed plans and automated Vehicle Videolog; GIS-based utility and sign inventories	Automated Vehicle Inventory Systems; CADD files;
Slope	Amount of side slope (1:2,1:3,1:4,1:5, etc.)	±10%	When changed or newly constructed; periodic inventory	Low - generally not maintained	Roadway inventory (Generally not maintained)	Coding of Data from Plan Sets	As-designed plans and automated Vehicle Videolog; GIS-based utility and sign inventories	Automated Vehicle Inventory Systems; CADD files
Culvert /Drainage Structure Location	x, y coordinates	±0.1 m	When changed or newly constructed	High	Roadway inventory/Plans	Photolog (Videolog); Coding of Data from Plan Sets	GPS and Automated Vehicle Videolog; CADD Files	GPS for field work; Automated Vehicle Inventory Systems; CADD files
Culvert Type	Categorical	N/A	When changed or newly constructed	Medium to high	Roadway inventory/Plans	Photolog (Videolog); Coding of Data from Plan Sets	GPS and Automated Vehicle Videolog; CADD Files	GPS for field work; Automated Vehicle Inventory Systems; CADD files
- Pavement								
Location	Segment location	±10 m	When changed	Medium	Road inventory /Plans/Pavement Management System	None/(as built plans)	CADD Drawing	GPS
Lane	Lane number	Integer	""	High	Roadway inventory /Plans/PMS	Photolog (videolog)	CADD Drawing	None/CADD

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Type of pavement	Concrete, Bituminous	Categorical	Every 1 to 3 years	Medium to High	Roadway inventory /Plans/PMS	Automated Vehicle/ Videolog Remote Sensing	Pavement Management Inventories; CADD Files	Automated Vehicle Videolog; Remote Sensing
Pavement surface condition	Categorical	Categorical	Every 1 to 3 years	Medium to High	PMS	Automated Vehicle/ Videolog	Pavement Management Inventories	Automated Vehicle Videolog Remote sensing
Skid number	Skid number of pavement	Skid number	3 years	Medium to low	PMS	Automated vehicle	Pavement Management Inventories	Remote sensing
Pavement markings	Description of current pavement markings	Categorical	Annual	Medium to low	PMS	Videolog	Pavement Management Inventories	Automated vehicle
Longitudinal Alignment								
Horizontal Alignment								
Location of Curve	Centerline Station of PC and PT (x, y, z coordinates of PC, PT, PI)	±1 m	Once- as changed or newly constructed	Medium to High	Roadway Inventory Design Plans (coded); often not maintained	Videolog; Coding of Data from Plan Sets	As-designed/build CADD Files; Field or Aerial Inventory	Direct input of CADD Design data; Automated Vehicle Inventory for QA/QC; Aerial or Satellite Imaging for QA/QC

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Type of Curve	Circular, Spiral, Parabolic; Other	Categorical	As changed or newly constructed	Medium to High	Roadway Inventory Design Plans (coded); often not maintained	Videolog; Coding of Data from Plan Sets	As-designed/built CADD Files; Field or Aerial Inventory	Direct input of CADD Design data; Automated Vehicle Inventory for QA/QC; Aerial or Satellite Imaging for QA/QC
Radius of Curve	Radius (m)	±10 m	As changed or newly constructed	Medium to High	Roadway Inventory Design Plans; often not maintained	Videolog; Coding of Data from Plan Sets	As-designed/built CADD Files; Field or Aerial Inventory	Direct input of CADD Design data; Automated Vehicle Inventory for QA/QC; Aerial or Satellite Imaging for QA/QC
Bearing of Tangent	Azimuth or Bearing Angle	±1 degree	As changed or newly constructed	Low-- Data Generally Not Maintained	N/A	None	As-designed/built CADD Files; Field or Aerial Inventory	Direct input of CADD Design data; Automated Vehicle Inventory for QA/QC; Aerial or Satellite Imaging for QA/QC

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Vertical Alignment								
Grade	Percent Grade in Direction of Milepost or Station	±0.1%	As changed or newly constructed	Low- to medium; generally maintained only as categorical	Design Plans Roadway Inventory Videolog	Videolog; Manual coding of design data	As-designed/built CADD Files; Field Inventory	Direct Input of CADD Design Data; Automated Vehicle Inventory
Location of Vertical Curve	Centerline Station of V.I., V.C., VAT; x, y, x coordinates of V.I., V.C., VAT	±1 m	As changed or newly constructed	Low- Data Generally Not Maintained or Maintained as Categorical	Design Plans Roadway Inventory	Videolog; Manual coding of design data	As-design/built CADD Files; Field Inventory	Direct Input of CADD Design Data; Automated Vehicle Inventory
Length of Vertical Curve	Length in meters	±1 m	As changed or newly constructed	Low- Data Generally Not Maintained	Roadway Inventory/Design Plans	Videolog; Manual coding of design data	CADD Files; Field Inventory	Direct Input of CADD Design Data; Automated Vehicle Inventory
Stopping Sight Distance (SSD)	Minimum available S.D. in meters per AASHTO criteria (one value for length of vertical or horizontal curve)	±1 m	As changed or newly constructed	Low- Data Generally Not Maintained	Derived from Design Plans (calculated from curve data). One value maintained.	Manual coding of design data	Design analysis of CADD files—SSD Profile from IHSDM	Direct Input of CADD Design Data; Automated Vehicle Inventory; IHSDM Output Direct to Files (provides continuous value of SSD)

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Passing Sight Distance (PSD)	Available PSD in meters per AASHTO criteria	±1 m	As changed or newly constructed	Low- Data Generally Not Maintained	Derived from Design Plans (calculated from curve data)	Coded data from Design Plans Manual coding of design data	Design analysis of CADD files—PSD profile from IHSDM	Direct Input of CADD Design Data; Automated Vehicle Inventory; IHSDM Output Direct to Files (provides continuous value of PSD)
Intersections								
Location	Milepost or reference point for intersection of crossing facility (x, y, z coordinates of centerline crossing)	±1 m	As changed or newly constructed	Medium to High	Roadway Inventory/Design Plans ("minor" intersections often not maintained)	Videolog, Coding of Data from Plan Sets	CADD Files/Field or Aerial Inventories	Direct Input of CADD Design Data; GIS Inventory
Reference/ Name of Intersection	Label (State Route, Name, etc.)	NA	As changed	High	Official State/Other Maps (City, County)	Manual Coding	CADD Files/Field or Aerial Inventories	GIS Inventory
Traffic Control	Type of prevailing control (e.g. signal, two-way stop, all stop, yield, no control)	categorical	As changed	Low to Medium-- Signalized Intersection; Others Generally Not Maintained	Roadway Inventory; sign inventory	Videolog, Coding of Data from Plan Sets	Inventory from Automated CADD Files and automated sign inventories	Automated Vehicle Videolog; GIS-based inventory
Angle of Intersection	Degrees	±5°	As alignment is changed or newly constructed	Low-- Typically Not Maintained	N/A	N/A	CADD Files; GIS Records of Network	CAD Design Data, Aerial/Satellite Imaging for QA/QC

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Intersection Sight Distance (all applicable)	Available ISD per AASHTO or Agency Criteria	±1 m	As alignment or roadside is changed; periodic inventory	Low--Data Not Typically Maintained	Special Field Studies Only (spot location)	Survey of Sight Lines	CADD Files of Design Drawings and base map; automated vehicle inventories; measurements from IHSDM or 3D visualization of design.	3D Visualization of CADD Files; IHSDM Output Direct to Files
Railroad Grade Crossings								
Location	Milepost or Reference for Intersection; x, y, z coordinates of centerline intersection	±1 m	As changed	High	Roadway Inventory	Videolog	CADD Files/Field or Aerial Inventories	Direct output of CADD Design Data
Number of Tracks		Categorical	As changed or newly constructed	High	Roadway Inventory	Videolog	CADD Files/Field or Aerial Inventories	Direct output of CADD Design Data
Type of Control	None, flashers, gates, etc.	Categorical	As changed	High	Roadway Inventory	Field Inventory; manual coding of plans	Videolog	None
Approach Sight Distance	Available sight distance for vehicles on approach	±10 m	As changed	Low	Data Generally Not Maintained	None	CADD Files and Base Map	3D Visualization of CADD Files
Trains per Day	Number of trains at crossing per day; time of crossing	±20%	Annually	Low	Railroad Records	Manual of coding of RR records	Automated Counters; GPS receives on trains	Direct Input of Train Data to Data (time) Warehouse
Average speed of trains	Speed of trains	±10 km/h	Annually	Low to Medium	Data generally not maintained Railroads; speed studies	Field Inventory	Automated Counters; GPS	Direct data linkage of railroad records to data warehouse

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Status of Track	Active/Inactive; Trains per week	Exact	Annually/As Changed	High	Railroad records	Manual Coding of Data	None	Direct data linkage of railroad records to data warehouse
Traffic Demand								
Average Daily Traffic and Hourly Measures	24-hour (adjusted for time of year and vehicle classification) traffic volumes	±5%	Annually to every 3 years (based on location)	Low to Medium (generally not enough counts and much data not gathered)	Automatic traffic recorders; special project counts; other coverage spot counts	Loop Detectors w/automatic recorders along highway at fixed locations; manual count	All signalized Intersection controllers; Automatic traffic recorders; Satellite Surveillance	Video automated traffic recorders at signals; Satellite Imaging
Vehicle Classification Counts	24-hour traffic by type of vehicle categorized by axles, load limits	±5% for each vehicle type	Annually to every 3 years (based on location)	Medium (not enough counts)	Automatic traffic recorders; weigh station data	Loop Detectors; spot visual counts (manual)	Automatic Traffic Recorders at all signalized intersections; Satellite Surveillance	Video automated traffic recorders at signals, satellite imaging; instrumented vehicles
Peak Period Traffic Counts	Demand Volume for highest hour volumes of day (including turning movements at intersections)	±5% vph for clock hours	Annually to every 3 years (based on location)	High	Automatic traffic recorders; weigh station data; special studies	Loop Detectors; spot visual counts (manual)	All signalized Intersections to nearest peak 60 minutes	Video automated traffic recorders at signals, satellite imaging; instrumented vehicles

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Approach Speed Distribution	Mean, Median, PARE, 85th percentile Speed	±1 km/h	Annually	Low-Generally Not Collected and Maintained	Special Studies Only/Automated Volume Density Recorders	Automatic Traffic Recorders; Radar	Video Surveillance, Satellite; Automatic Recorders	Video automated traffic recorders; satellite imaging
Traffic Control Devices								
Warning and Regulatory Signs								
Location	Milepost or reference (by direction of travel) x, y, z coordinates	±1 m	Every 1 to 3 years; As changed	Medium to Low (often not maintained)	Periodic Field Sign Inventory/ Videolog	Videolog, Field Survey (manual)	GIS-Based Sign Inventory; Maintenance Inventory	Automated Videolog; Direct Input of Maintenance Records
Message	MUTCD Code	Exact (Code must be correct)	Every 1 to 3 years; As changed	Medium to Low (often not maintained)	Periodic Field Sign Inventory/ Videolog	Videolog, Field Survey (manual)	GIS-Based Sign Inventory; Maintenance Inventory	Automated Videolog; Direct Input of Maintenance Records
Sign Dimensions	MUTCD Code Reference	Exact	Every 1 to 3 years; As changed/ replaced	Medium to Low (often not maintained)	Periodic Field Sign Inventory/ Videolog	Sign Inventory (Videolog)	GIS-Based Sign Inventory; Maintenance Inventory	Automated Videolog; Direct Input of Maintenance Records
Reflectivity	Amount of reflectivity from the sign	Reflectivity measure	1 to 3 years	Low	Generally Special Field Studies Only	Reflectometer; Automated Vehicle Inventory	Automated Vehicle Inventory	Light Meters
Condition	Categorical	Categorical	1 to 3 years	Low	Generally Special Field Studies Only		Automated Vehicle Inventory	Light Meters

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Pavement Markings								
Type	Centerline, Edge, Crosswalk, Etc.	Categorical	Every 1 to 3; As Changed	Medium (often not maintained)	Design Plans, Inventory	Visual Field Inventory	GIS-Based Inventory; Maintenance Records	Automated Vehicle Videolog; direct Input of Maintenance Records
Color	White, Yellow, Other	Expect	As Changed	Medium (often not maintained)	Design Plans, Inventory	Visual Field Inventory	GIS-Based Inventory; Maintenance Records	Automated Vehicle Videolog; Direct Input of Maintenance
Width	Width of Stripe	± 0.1 m	Every 1 to 3 years; As Changed	Low—Generally not maintained	Design Plans, Field Inventory	Visual Field Inventory	GIS-Based Inventory; Maintenance Records	Automated Vehicle Videolog; Direct Input of Maintenance Records
Reflectivity	Amount of reflectivity from the sign	Reflectivity measure	6 mos. to 2 years	Low—Generally not maintained	Design Plans, Field Inventory	Visual Field Inventory	GIS-Based Inventory; Maintenance Records	Automated Vehicle Videolog; Direct Input of Maintenance Records
Condition	Condition of the markings	Categorical	6 mos. to 2 years	Low—Generally not maintained	Design Plans, Field Inventory	Visual Field Inventory	GIS-Based Inventory; Maintenance Records	Automated Vehicle Videolog; Direct Input of Maintenance Records

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Message	"Only," "Stop," Etc.	Categorical	6 mos. To 2 years	Low—Generally not maintained	Design Plans, Field Inventory	Visual Field Inventory	GIS-Based Inventory; Maintenance Records	Automated Vehicle Videolog; Direct Input of Maintenance Record
Overpass/Underpass (Bridge)								
Location	Reference Point for crossing facility; x, y, z coordinates of crossing	± 1 m	As changed or newly constructed	High	Design Plans, Field Surveys	Coding of Data from Plan Sets	As Designed CADD Plan Files	CADD Files; Direct Input of Bridge Inspection Reports
Type	roadway over, railroad over, etc.	Categorical	As changed or newly constructed	High	Design Plans, Field Surveys	Coding of Data from Plan Sets	As Designed CADD Plan Files	CADD Files; Direct Input of Bridge Inspection Reports
Critical vertical clearance	Traveled way to point of minimum clearance	± 1 cm	As changed or newly constructed	Medium	Design Plans, Field Surveys,	Coding of Data from Plan Sets	As Designed CADD Plan Files	CADD Files; Direct Input of Bridge Inspection Reports
Horizontal clearance	Edge of pavement to parapet, rail	± 0.1 m	As changed or newly constructed	Medium	Design Plans, Field Surveys,	Coding of Data from Plan Sets	As Designed CADD Plan Files	CADD Files; Direct Input of Bridge Inspection Reports

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Weight restriction	Posted vehicle weight limitations	± 1 K	1-2 years; As changed	High	Periodic Manual Bridge Inspections	Coding of Data from Plan Sets	As Designed CADD Plan Files	CADD Files; Direct Input of Bridge Inspection Reports; In-place monitoring of bridge performance
Agency Responsibility - General								
Location being/end	Beginning and ending points of the location	±10 m	When changed	Medium	Roadway Inventory/Maps /Pavement (Bridge, etc) Management Systems	None	CADD files	GPS
Classification	Type of location, e.g. intersection, ramp, etc.	Categorical	Once	High	Roadway Inventory, etc.	Photolog	CADD files	CADD
Agency responsible for design	Name of agency	None	When changed	High	Files	None	None	None
Agency responsible for maintenance	Name of agency	None	When changed	High	Files	None	None	None
Agency responsible for operation	Name of agency	None	When changed	High	Files	None	None	None

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

Information Element	Description	Safety Related Requirements		Current Collection			Future	
		Dimension	Collect. Freq.	Quality	Sources (primary/ secondary)	Technologies Used	Sources	Technologies Used
Agency responsible for traffic enforcement	Name of agency	None	When changed	Low	Files	None	None	None
Date of original construction	Date of first construction	mm:yy	Once	High	Files/Roadway Inventory	None	None	None
Additional comment	Commentary about the section	None	When entered	Medium	Files/Roadway Inventory	None	CADD files	Voice interpretation
- Changes								
Date of change	Date change made	mm:yy	Date of change	Medium	Roadway Inventory	None	CADD files	CADD
Type of change	Description of change made	None	Date of change	Medium	Files	None	CADD files	None
Comments and Complaints								
Location	Location on roadway that the comment or complaint references.	±15 m	Once per Complaint	Low	Telephone; maintenance log; office file of letters	Telephone; mail	Automated computer log of correspondence; Website to register comments	Voice interpretation; GPS with error correction.; Internet
Date	Date of comment.[10]	dd/mm/yy	Once	High	Telephone; maintenance log	Telephone	Automated computer log	Computer clock
Source	The person or organization that made the complaint.	Categorical	Once	High	Telephone; maintenance log	Telephone	CADD files	Voice interpretation
Nature of comment or complaint	Description of the complaint.	Categorical	Once	Medium	Telephone; maintenance log	Telephone	CADD files	Voice interpretation

1. For the Police Crash Report (PCR), data are collected only once, usually at the time the report is taken. However, additional elements may come from supplemental reports (usually only in the case of severe crashes) and from witness statements.

TABLE D-1 Characteristics of crash and roadway: crash report and roadway inventory (*Continued*)

2. Location remains an unclear element and is interpreted as the first harmful event, most harmful event, final resting place of vehicles, or approximate location where the crash appeared to have occurred. It should be dropped in favor of first and most harmful event. The gathering of such data from the police, however, remains problematical.

3. "Categorical" means that the entry is correct for the categories used.

4. A Fatal Accident Reporting System (FARS) report is prepared for every vehicle crash which involves a fatality occurring within 30 days of the crash and which has been investigated by the police. The report is comprehensive and data gathered by trained personnel. Its data has high quality.

5. Department of Motor Vehicles, to include driver licensing as well as vehicle registration.

6. The traditional KABCO severity scale presents gross measures of injury and is highly dependent upon training of investigators and policy for recording injuries. Many injuries are not reported.

7. Usually combined with or shown only as most harmful event.

8. Supplemental investigations may be done in the event of a serious injury or fatal crash.

9. May be relatively accurately located when first installed, but may not be updated when replaced. Natural appurtenances may not be located.

10. The date may be important for tort purposes. Possibly of greater importance is the frequency of complaints at the location.

APPENDIX E

ISSUES ASSOCIATED WITH THE COLLECTION AND MANAGEMENT OF DATA

COLLECTION AND MANAGEMENT OF ROADWAY DATA

1. Lack of use of precision measurement devices
2. General lack of automated tools for collection and management
3. Inaccuracies resulting from:
   a. Lack of care by those collecting the data in the field
   b. Reliance on nonfield data, primarily submissions of as-built plans, for many highway data-elements
   c. Infrequent updates of field-measured highway data
   d. Failure to provide notification of, and information about, changes made to the facility
4. Lack of coverage of the highway network
5. Incomplete data, especially with respect to longitudinal geometrics and appurtenances
6. Lack of integration of sources of highway-inventory data
   a. Inventory file
   b. Video log
   c. Special inventory files (e.g., guardrails)
   d. Maintenance files
7. Limited feedback regarding accuracy of recording reduces the likelihood of collecting high-quality data
8. Lack of history

COLLECTION AND MAINTENANCE OF TRAFFIC AND CONTROL DATA

1. Lack of precision of the data
   a. Only ADT provided (while design-hour and turning-movement volumes may be desired, as well as data on vehicle mix)
   b. Lack of detail on signal timing
2. Incompleteness of the data—only type of intersection control provided (resulting in lack of detail on other traffic controls present)
3. Lack of coverage of the highway system (either through direct measurement or through estimates using data from adjacent count locations)
4. Lack of history of traffic and control conditions at a given location

COLLECTION OF DATA FOR TRAFFIC CRASH HISTORY

1. Potential conflict among officers' roles at a crash scene may degrade the quality of safety data collected
2. Perceived need by the officer to establish fault, for insurance and enforcement purposes, may bias the collection and interpretation of data
3. Lack of incentive to officer to maintain data quality
4. Inconsistent coverage of vehicular crashes yields biased samples (variation over time, by severity, and with local conditions such as weather)
5. Inaccuracy and imprecision in locating the crash and the sequence of events involved, positions of vehicles, and persons involved in the crash
6. Inadequate training of officers to achieve quality crash-data collection
7. Adequate tools or means for collecting some of the data are not available, resulting in low quality including inaccurate or incomplete data
8. Completeness of the report is reduced, for lack of follow-up, when some data must be collected away from the scene of the crash
9. Sources of data may not be readily accessible to the crash investigator
10. Officers are sometimes required to make judgements for which they do not have adequate training
11. Lack of linkages with other databases results in officers collecting data that are already available and usually in a more accurate and precise form
12. Poorly defined and inappropriate data elements and codes contribute to incomplete, inconsistent, and inaccurate recording
13. Size and complexity of crash reports appear to be directly related to the likelihood of incomplete or inaccurate responses
14. Reporting data which are also available from other sources or multiple recording of the same data increases the likelihood of inconsistency among data sources
15. Disturbance or destruction of evidence at the scene by traffic, fire, rescue, tow vehicle operators, as well as inexperienced police officers
16. Lack of codes or elements for specific needs results in loss of data
17. Completing report away from scene results in problems with accuracy and completeness because of failure to collect or forgetting data

MANAGEMENT OF DATA FOR TRAFFIC CRASH HISTORY

1. Local agencies enter data into their files prior to transmitting reports to the state, thereby increasing delay in availability at state level

2. Maintenance of paper files can reduce flexibility in access and use of local data
3. The number of steps required for handling reports increases delay and likelihood of errors
4. Separation of duties among state agencies for recording data allows differing levels of quality and timeliness at the state level
5. Multiple databases, particularly local and central, increase delays in data availability centrally and increase handling of data
6. Use of outdated database management systems reduces the likelihood of making changes and usually precludes linkages. It also can restrict the number of years of history maintained.
7. Editing is performed without access to original facts, which limits ability to provide accurate and precise data.
8. Lack of automated assistance increases time required to process reports, particularly for location coding.
9. Paper files are the primary source of crash narrative and diagram, limiting general availability of these two elements to users who need them for site analysis.
10. State-level processing is not integrated with local level, reducing availability of feedback needed for improving quality and quality assurance.
11. Change in forms without adequate review of entire process results in loss of data or decreased quality of the data.
12. Review and quality control varies depending on attention and priority given to crash reporting by agencies.
13. Lack of direct access by users reduces availability of feedback needed to address quality as well as usefulness of data being recorded.

USE OF HIGHWAY SAFETY DATA

1. While most designers have a basic level of computer literacy, to be able to use the software for accessing safety data and to be able to employ it effectively usually require extensive training and frequent use.
2. Some safety data systems are not designed for end-user access, thus requiring the user to rely on intermediaries and eliminating interactive analysis.
3. It is technically difficult to achieve a highly intuitive interface for a complex system (e.g., relating design activities and highway safety information)
4. The more difficult the system is to use, the less it will be used, or the more likely it will be operated only by a technically elite group rather than in an interactive manner by end users.
5. Lack of system coordination and integration is a major barrier to use, as it prevents real-time (or, possibly, any) linkages between roadway, crash, and other databases.
6. Due to inaccurate coding of crash data, designers of specific projects do not find data from crash systems acceptable and will, therefore, use significant resources to review crash reports for the site being studied.
7. Most designers are not well trained in analytical methods involving advanced statistics and evaluation methodology.
8. Most designers do not have an adequate understanding of the dynamics of highway operation to allow them to have solid judgement on the operational and safety impacts of their design.

APPENDIX F

APPLICABILITY OF CANDIDATE TECHNOLOGIES FOR IMPROVING THE QUALITY OF SAFETY DATA TO SUPPORT HIGHWAY DESIGN

TABLE F-1 Applicability of candidate technologies for improving the quality of safety data to support highway design

	Data Collection Technologies												
Issues Associated with the Collection and Management of Roadway Data	Portable Computers	Stripe or Bar-code Reader	Voice Recognition	Radio ID Chips	Smart Cards	GPS	Other Location Technologies	AI	Laser Measurement	Digital Photography	Aerial Imaging	Field Communication	Vehicle Monitoring Systems
1. Lack of precision measurement devices	x					x	x		x	x	x		
2. Lack of automated tools	x	x	x	x	x	x	x	x	x		x	x	
3. Inaccuracies													
a. Lack of care by collector		x		x	x	x	x	x	x	x	x	x	
b. Reliance on non-field data	x					x	x		x	x	x	x	
c. Infrequent updates	x					x	x		x	x	x	x	
d. Failure to notify of changes	x					x	x		x	x	x	x	
4. Lack of network coverage	x					x	x		x	x	x	x	
5. Incomplete data (longitudinal geometrics and appurtenances)						x			x		x		
6. Lack of integration of source data		x											
7. Limited feedback on accuracy													
8. Lack of history													

TABLE F-1 Applicability of candidate technologies for improving the quality of safety data to support highway design (*Continued*)

	Data Collection Technologies												
Issues Associated with the Collection and Management of Traffic and Control Data	Portable Computers	Stripe or Bar-code Reader	Voice Recognition	Radio ID Chips	Smart Cards	GPS	Other Location Technologies	AI	Laser Measurement	Digital Photography	Aerial Imaging	Field Communication	Vehicle Monitoring Systems
1. Lack of precision													
a. only ADT provided	x												
b. Lack of signal timing data													
2. Incompleteness of data			x			x	x	x	x	x			
3. Lack of system coverage	x		x			x	x	x					
4. Lack of history													
Issues Associated with the Collection of Data for Traffic Crash History													
1. Conflict among officer roles at scene													
2. Perceived need to establish fault								x					
3. Lack of incentive for collector			x					x					
4. Inconsistent coverage of crashes						x	x	x	x	x			x
5. Inaccurate and imprecise crash location		x		x		x	x	x	x	x		x	
6. Inadequate training of officers collecting data	x	x		x	x			x					x

TABLE F-1 Applicability of candidate technologies for improving the quality of safety data to support highway design (*Continued*)

	Data Collection Technologies												
Issues Associated with the Collection of Data for Traffic Crash History	Portable Computers	Stripe or Bar-code Reader	Voice Recognition	Radio ID Chips	Smart Cards	GPS	Other Locn. Technols.	AI	Laser Measurement	Digital Photography	Aerial Imaging	Field Communication	Vehicle Monitoring Systems
7. Inadequate tools provided to collector	x	x	x	x	x	x	x	x	x	x		x	x
8. Incompleteness due to lack of follow-up work	x	x		x	x								
9. Data to complete form not readily accessible		x		x	x							x	x
10. Officer not qualified to make required judgments								x					x
11. Lack of linkages with other databases	x	x		x	x							x	x
12. Poorly defined and inappropriate data elements and codes		x		x	x			x					
13. Crash reports too large and complex	x	x	x	x	x			x					x
14. Duplication of data collection causes inconsistency		x		x	x							x	x
15. Destruction of evidence during operations at the scene			x						x	x			x
16. Lack of codes for specific needs			x					x					x
17. Completion of report off-scene leads to inaccuracies and incomplete data		x	x	x	x	x	x	x	x	x			x

TABLE F-1 **Applicability of candidate technologies for improving the quality of safety data to support highway design** (*Continued*)

	Data Management Technologies										
Issues Associated with the Management of Data for Traffic Crash History	Optical Scanners	OCR	OMR	AI	Error Trapping Software	Rela-tional DB's	Object Oriented DB's	Distrib-uted DB's	GUI	GIS	CADD
1. Local agencies hold report for own entry, causing delay	x	x	x					x	x		
2. Paper files reduce flexibility	x	x	x								
3. Too many steps in processing, causing delay and error		x	x		x			x			
4. Entry by different agencies in state, causing variable quality and delay	x	x	x		x			x	x		
5. Multiple databases result in inefficiency						x		x			
6. Outdated DBMS's create resistance to change and linkages						x	x	x		x	x
7. Editing without access to original source				x				x			
8. Lack of automated process, especially for location coding	x	x	x	x	x					x	x
9. Narrative and diagram only available on hard copy of report	x	x					x				
10. State and local processing not integrated, reducing feedback for corrections at local level	x	x						x			
11. Change in forms without adequate review of entire process results in loss of data or decreased quality of the data.											

TABLE F-1 Applicability of candidate technologies for improving the quality of safety data to support highway design (*Continued*)

	Data Management Technologies										
Issues Associated with the Management of Data for Traffic Crash History	Optical Scanners	OCR	OMR	AI	Error Trapping Software	Rela-tional DB's	Object Oriented DB's	Distrib-uted DB's	GUI	GIS	CADD
12. Review and quality control varies, dependent upon attention and priority given to crash reporting by agencies.				x	x						
13. Lack of direct access by users reduces feed-back needed to address quality as well as usefulness of data being recorded.	x	x			x				x		
Issues Associated with the Collection and Management of Roadway Data											
1. Lack of precision measurement devices											
2. Lack of automated tools											
3. Inaccuracies											
a. Lack of care by collector											
b. Reliance on non-field data											
c. Infrequent updates											
d. Failure to notify of changes											
4. Lack of network coverage											
5. Incomplete data (longitudinal geometrics and appurtenances)											

TABLE F-1 Applicability of candidate technologies for improving the quality of safety data to support highway design (*Continued*)

	Data Management Technologies										
Issues Associated with the Collection and Management of Roadway Data	Optical Scanners	OCR	OMR	AI	Error Trapping Software	Rela-tional DB's	Object Oriented DB's	Distrib-uted DB's	GUI	GIS	CADD
6. Lack of integration of source data						x	x	x		x	x
7. Limited feedback on accuracy											
8. Lack of history						x					
Issues Associated with the Collection and Management of Traffic and Control Data											
1. Lack of precision											
a. only ADT provided											
b. Lack of signal timing data											
2. Incompleteness of data											
3. Lack of system coverage											
4. Lack of history						x					

TABLE F-1 Applicability of candidate technologies for improving the quality of safety data to support highway design (*Continued*)

	Information Retrieval Technologies									
Issues Associated with the Use of Highway Safety Data	Traditional GUI	CADD with 3D and 4D	Virtual Reality	GIS	AI	Context Sensitive Help	Voice Recog-nition	Model-ing Tools	Simu-lation	Neural Net-works
1. Lack of end-user orientation	x	x	x	x	x	x	x			
2. Intermediary required between end-user and system	x	x	x	x	x	x	x			
3. Intuitive interface is difficult to have for complex system	x	x	x	x	x	x	x			
4. The more complex the system, the less likely it will be used	x		x		x	x	x			
5. Lack of system coordination and integration is a barrier to use		x		x	x					
6. Inaccurate coding results in major effort to review original crash reports					x					
7. Designers not well trained in analytical methods					x	x		x	x	x
8. Designers do not have good understanding of dynamics of highway operation		x	x		x			x	x	x

APPENDIX G

SYSTEM GOALS AND OBJECTIVES

Goal A: The system will deliver information to the user that is useful for the particular stage and activity of the design process

Objectives for Use

1. Provide data for project work sufficient to produce complete graphic (three-dimensional and animated) views of the site that depict the true condition for the time period being represented by the data set.
2. Provide data in a form suitable for systemic and project-level analyses that use computational methods.
3. Facilitate identification of systemic problems (e.g., need to alter design policy).
4. Facilitate identification of hazardous locations.
5. Facilitate identification of conditions and circumstances that contribute to a hazardous condition at a location.
6. Facilitate derivation of statistical relationships that allow modeling of the impact on highway safety of design actions.
7. Facilitate estimates of costs associated with a design.
8. Provide data that meet quality requirements [accurate, precise, complete, timely, comprehensive (coverage of the target population, that is, crashes and roadways)].

Goal B: The system will facilitate the integration of multiple data sources into the design process

Objectives for Use

1. Allow seamless linkage with other safety data, in terms of both relating to conditions over time and to location of crash events in space. Provide these linkages so that the data may be used in both graphic representation and computational use.
   a. Crash
   b. Maintenance
   c. Complaint
   d. Administrative
2. Allow seamless interaction with design tools.
3. Integrate system operation with the design process.
4. Provide data and information useful to address each step in the design process (format and content).

Goal C: The system will facilitate direct use by decision-makers

Objectives for Use

1. Provide assistance to the decisionmaker in applying the safety data at each step in the design process.
2. Provide assistance to the decisionmaker in making design decisions.
3. Provide a user interface that allows direct, intuitive, and interactive involvement by the decisionmaker.

Goal D: Establish and maintain a system to collect and manage safety data to support design decisions

Objectives for Use

1. Establish and maintain a program to provide for the collection of the safety data needed for the system.
   a. Personnel
   b. Equipment
   c. Training
   d. Guidelines and specifications
   e. Funds
2. Establish and maintain a program of quality assurance.
3. Maintain the security of data used in the system.
   a. Comprehensive access and maintenance security system
   b. Regular monitoring of system use

Goal E: The system will be feasible to implement

Objectives for Use

1. The system will be economically feasible (keep system cost within budget constraints-development, capital, operating, and maintenance).
2. The system will be operational within a desired time-frame (keep development and implementation within time constraints).
3. The system will not require specialized capabilities of a type, and at a rate, that is not available to develop, operate, and maintain (keep personnel requirements for system development, operation, and maintenance within human resource constraints).
4. The system will be readily adaptable to changing data needs, collection methods, and other attributes of its environment.

Goal F: The system will meet requirements and constraints of the organizational context in which it operates

Objectives for Use

1. The system will be designed to be as flexible as possible to fit into varying organizational structures.
2. The system will be designed to be as flexible as possible to fit into varying design processes.
3. The system will be designed to be as flexible as possible in adjusting to changing design policies and procedures.
4. The system will coordinate efforts to collect, maintain, and use safety data with other agencies that are collectors and users of the data.

APPENDIX H

FUNDAMENTAL ARCHITECTURE OF THE DDSS

EXAMPLES OF PROCESSES

The design decision support system (DDSS) is structured to assist the designer at the various stages of the design process. It will be capable of generating information at various levels of detail from the most aggregate to the most disaggregate. This will allow the user to perform a series of inquiries in a given area, each of which would enable the user to "drill down" further into the details available in the data set. To demonstrate this concept further, several separate key activities performed in the design process are diagrammed, and the processes described, indicating how the DDSS would assist the designer. This demonstration of system operation provides further documentation of the fundamental architecture of the system being proposed.

The following five scenarios were selected:

- High-hazard location identification,
- Problem identification for a project,
- Preliminary design project,
- Analysis of a design exception, and
- Development or refinement of design standards and criteria.

High-Hazard Location Identification (HHL-ID)

A common task in the planning stages of the design process involves identifying locations that are potentially hazardous on the basis of crash experience. This is a reactive activity, which relies upon rigorous analysis of crash records over recent years. The analysis is performed at an aggregate level (i.e., it is not usually feasible to consider details regarding each site, because so many sites are included in the analysis). Use of the DDSS will, however, allow designers to consider more detail than is currently feasible. Later stages of the process will allow for even more detailed consideration of each site as the designer's focus narrows.

The HHL-ID process usually requires limited information about design and traffic attributes at specific locations, including some history about these site attributes. The end result of HHL-ID is a list of locations that become candidates for action and, which therefore are subjects for more detailed analysis. Figure H-1 provides a schematic overview of this process described below.

The analyst interacts with the DDSS through the GIS. The subject area can be selected using GIS mapping or by directly entering descriptors. An HHL-ID algorithm is used to extract data on crashes, including some disaggregation by type, and combines them with traffic data to calculate appropriate rates.

It is beyond the scope of this project to develop or recommend a particular algorithm for doing an HHL-ID. Most agencies currently employ one or more methods for systematically identifying HHLs. Each agency can include its chosen method as a module in this system.

Current methods commonly produce a prioritized list of candidates. This analysis is often done separately for road segments and intersections. Road segments can be analyzed as individual links between intersections and combined to create a route. Areawide analyses are also possible.

Once a list is generated, however, the process usually requires additional checking. This is because the validity of the results are questioned or there is a desire to arrive at a preliminary view of possible actions to be taken at the sites. The latter task helps to derive order-of-magnitude estimates of costs for possible actions. Cost estimates are often used for project programming decisions (an activity external to the process being described here). The system will be designed to facilitate those additional steps as well.

Using GIS output to display the results of the HHL-ID routine will produce a highly graphic result, primarily in the form of color-coded maps indicating the highest hazard sites. Each node, link, route, corridor, and area, so identified, will be *hyperlinked* to further details from the HHL-ID analysis. They, in turn, will be further hyperlinked to details about each of the sites. Hyperlinking allows the analyst to use a pointing device, such as a mouse, to select a link, node, corridor, or area, and have further details about that subject site immediately generated. Some of these summary data will be similar to those generated in other processes, as discussed below.

The analyst will be able to study each site individually and efficiently, through one or more displays (windows and/or screens). This allows the analyst to quickly become more familiar with the sites being considered. Specific purposes for these displays are to allow the analyst to do as follows:

- Check the automated analysis, done as part of the HHL-ID algorithm, to be assured that it was properly employing and interpreting the information. Although the routines may be adequate for most sites, it is necessary to allow for unforeseen circumstances at some sites, which may make

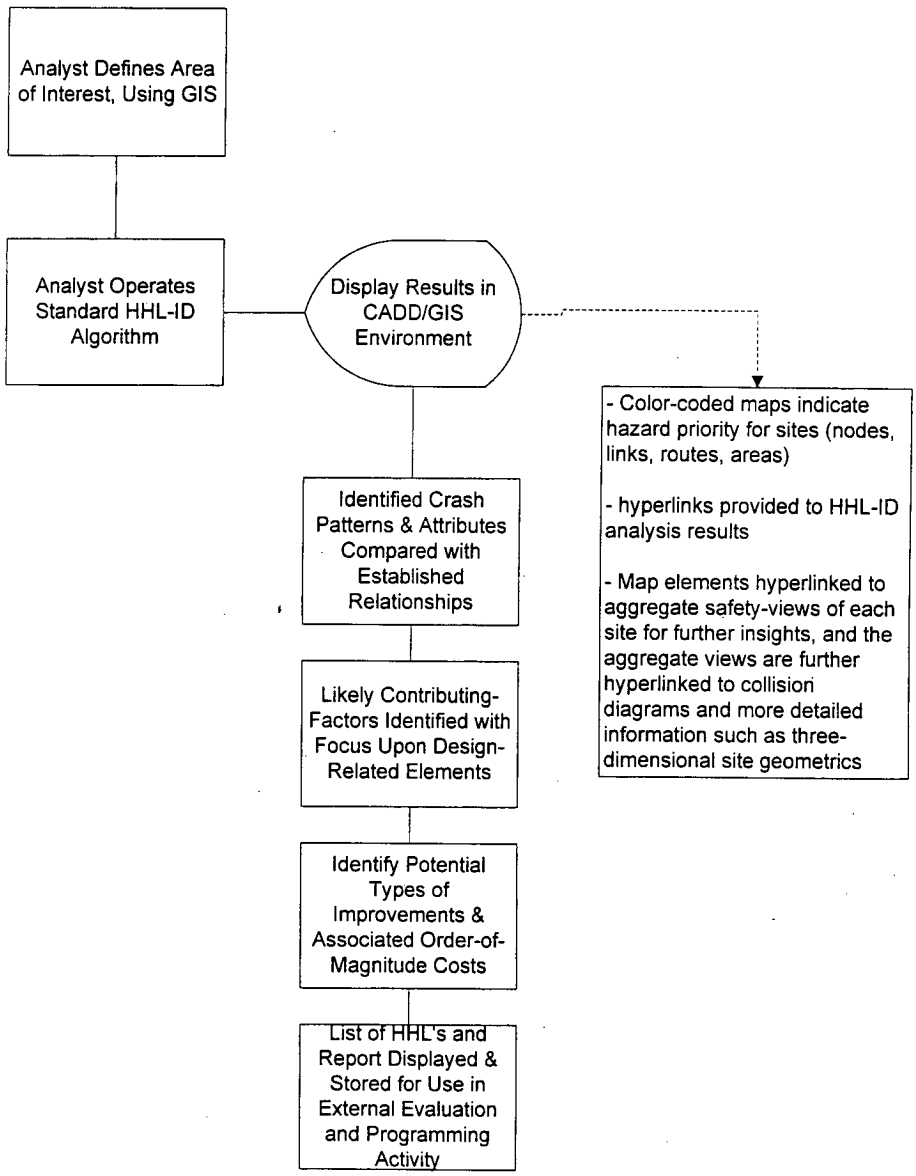

Figure H-1. Example system use identification of high-hazard locations for possible action.

the commonly used method inappropriate. For example, the occurrence of certain crashes may have been due to temporary circumstances not ordinarily encountered and which may not be accounted for adequately in the algorithm. The analyst may want to draw out related information from the system regarding accident migration and recent project history to help validate the list.

- Check underlying crash data to be assured that they seem valid and that biases were not created because of external conditions that may result in reporting bias in a particular jurisdiction.
- Gain a direct sense of how the likely contributing circumstances relate to site conditions.
- Determine if there may be other extenuating circumstances that suggest that the ranking of a particular site either does or does not seem appropriate. This means that the analyst will have the ability to access the results of the analyses even for those sites not highlighted as candidate HHLs.
- Manually intervene in the ranking results and make adjustments, including documentation of the bases for the changes.
- Perform sensitivity analyses, with respect to such parameters as crash-frequency thresholds, or the quality-control threshold (which determines if a site will be included in the list of candidates).

The analyst can then make preliminary conclusions about the likelihood that design or operational improvements might reduce hazards at a site. Ultimately, the AI features of the system will provide a highly interactive environment in which the analyst will be given recommendations about many of the things in the list above, as well as the likely linkages with contributing factors (and the probability associated with that likelihood). Before that capability is fully available, there is an evolutionary path to follow. Initially, reliance is placed solely on the analyst's knowledge and experience, providing that person with the environment best suited to using his or her capability. It can progress to include provision of reference material, within the graphic CADD/GIS environment, tabulating linkages to contributing factors. The basis for establishing those linkages will evolve from merely documenting expert opinion to actions or suggestions more directly based on research.

With the assistance of the system, the analyst will interpret the possibilities of contributing factors based on the understanding achieved for each site. The analyst will then define one or more possible projects or treatments for each site. The projects will be defined in general terms, sufficient for this level of the process. Associated with each generic project type will be unit-cost factors which can be used to derive capital, operating, and maintenance costs. These will be maintained in the system and made available for use in programming decisions.

Figure H-2 provides another view of this process, using a "process dependency diagram." The sets of subprocesses involved in the determination and analysis of candidate HHLs are divided into four groups and further defined. The diagram provided here is a high-level depiction. The details of the processes are to be determined during the next stage of development of the system. However, the diagram does provide sufficient detail to indicate the types of displays intended, as well as some of the analytical aspects of the process.

For example, the subprocess for identifying potential site improvements and producing an order-of-magnitude cost for a potential improvement includes three discrete subprocesses within it.

1. The system will interact with the user to arrive at a list of suggested site attributes that relate to the contributing factors identified in the previous subprocess. In the most advanced technological form of the system, AI routines will suggest to the user an initial list, leaving it to the user to modify when appropriate. In the initial implementation of the system, however, the list to be provided to the user would probably be a reference of the type shown in Figure H-3. The example in the exhibit demonstrates that accepted relationships have existed for over 20 years. Several versions of this exhibit are available from the current literature. Work is currently underway, as part of the FHWA's effort to develop the IHSDM, to arrive at expert opinions on these types of relationships.
2. The system will interact with the user to identify potential types of site improvements. The level of analysis being conducted at this stage requires only that generic types of improvements be suggested.
3. A set of predetermined improvement cost factors, associated with the generic improvement types, will be applied to determine an initial estimate for each site, to assist in programming decisions. A final ranking of sites will be made according to an algorithm established by the agency.

The results of this subprocess will be used as input for the next process, which produces a final report listing HHLs.

Problem Identification for a Project

Table H-1 shows how a system user would apply the DDSS to identify likely factors contributing to hazard at a site. The process has some similarity to what is done when analyzing HHLs, but the level of detail is beyond what is usually feasible at the project programming stage. Furthermore, this process focuses only on the identification of problems and likely contributing circumstances. The method for linkage with potential design strategies is associated with the preliminary design process, which is discussed in the next section.

Using GIS and CADD, the site under study is displayed. The user can then request general summaries of crash experience at the site. Based on what these data indicate, the designer can request further details in the form of collision diagrams, bivariate graphs, and identification of over-represented patterns in the crashes. As desired, the designer may then look at individual crashes, reviewing the narratives and diagrams and seeing animation or simulation of selected crashes. Physical and operational information for the site can also be displayed as requested, including use of time lines, CADD/GIS overlays, standard graphics, and digital images. Each of the steps that drill deeper into the multidimensional crash data available in the system will often be accomplished by a simple hyperlink.

In addition to these information presentation tools, the module can also deliver an analysis to the designer, using safety-audit procedures. The detailed analysis tools that will be available include those which are the focus of development under the IHSDM project. Several of these are discussed further in the next example process.

The system will also provide designers with a tool to identify the link between crash history and likely contributing circumstances, as well as that between contributing circumstances and candidate countermeasures for consideration. This will be accomplished in a manner similar to the process described above. Expert system technology offers potential assistance here. Ultimately, these steps in the process will be

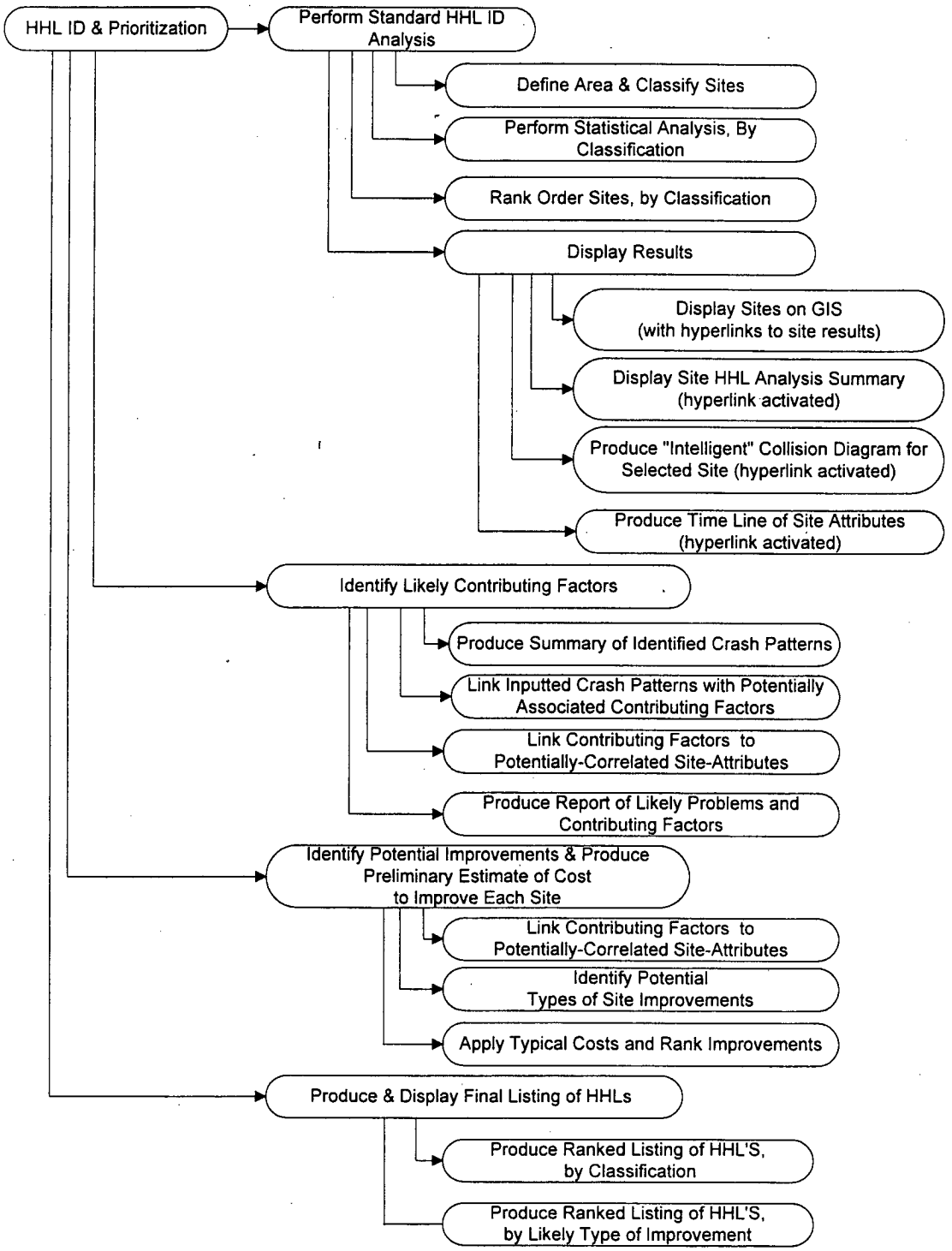

Figure H-2. High-level process dependency diagram for high-hazard location identification.

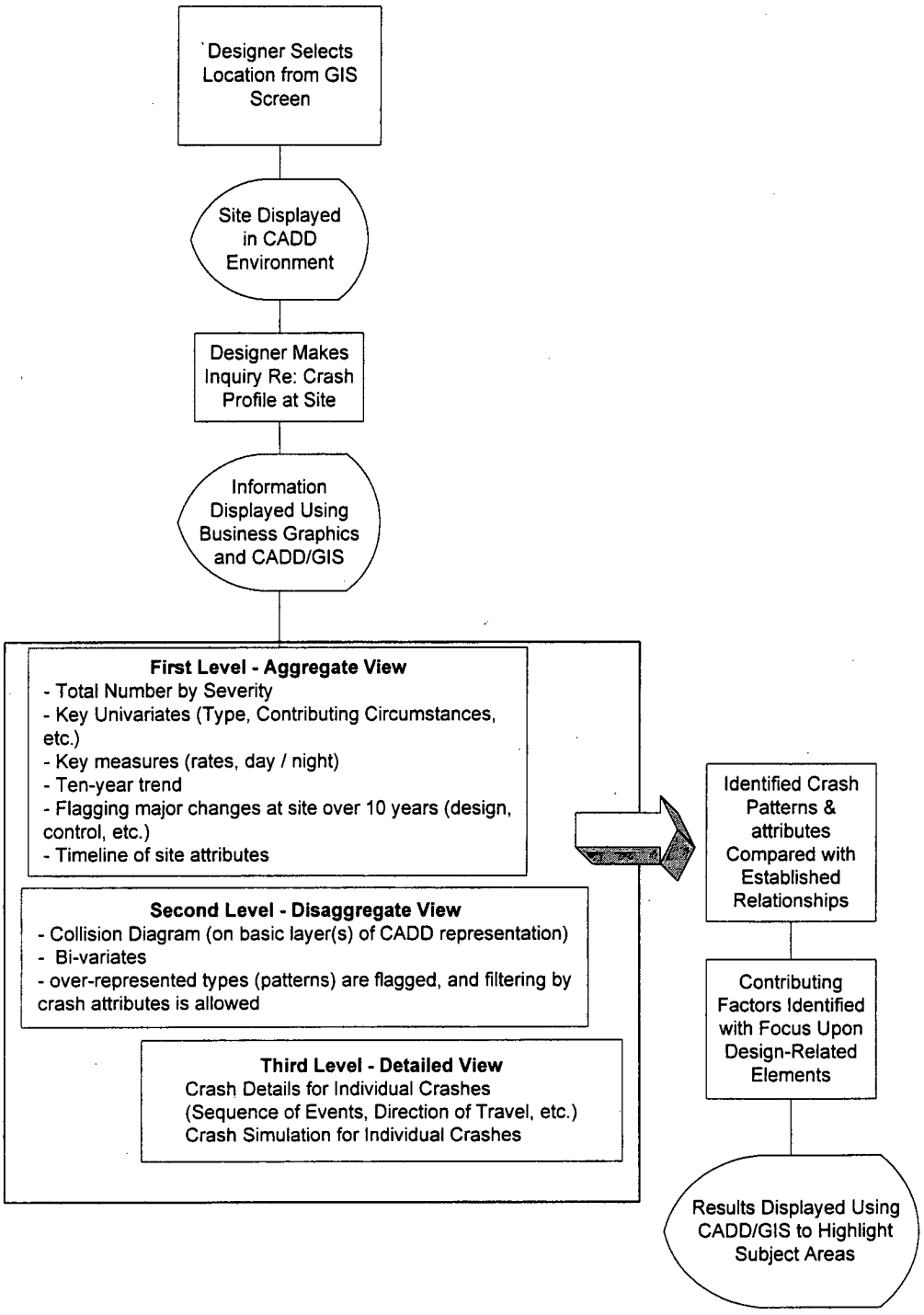

Figure H-3. Example system use problem identification for a project.

significantly aided by an artificial intelligence capacity. In the interim, however, as knowledge evolves of relationships, it will be included for the user in appropriate forms.

Figure H-4 displays a high-level process-dependency diagram for this activity. Several of the information display techniques described above are employed throughout this process. Hyperlinks between one level of detail and the next are a key feature. This allows a user ready access to information as desired. For instance, each crash depicted on the collision diagram will be hyperlinked to further details on the crash, so that when selected by the user, it will be displayed in a window. Similarly, a time line, of the type described earlier, will include

TABLE H-1 Example section of reference tables available to link crash patterns to contributing circumstances and potential improvements

Crash Pattern	Probable Contributing Circumstance	Potential Improvement
Right-Angle collisions at unsignalized intersections	Restricted sight distance	• Remove sight obstruction • Restrict parking near corners • Install stop signs (2) • Install warning signs (2) • Install/improve street lighting • Reduce speed limit on approaches (1) • Install signals (2) • Install yield signs (2) • Channelize intersection
	Large total intersection volume	• Install signals (2)
	High approach speed	• Reroute through traffic • Install rumble strips
Right-angle collisions at signalized intersections etc.	Poor visibility of signals etc.	Install advanced warning devices (2) etc.

Notes:
1. Spot-speed study should be conducted to justify speed limit reduction.
2. See MUTCD
3. Table adapted from Taylor, J.I., and H.T. Thompson. "Identification of Hazardous Locations - Final Report," Report No. FHWA -77-83, Federal Highway Administration, U.S. Department of Transportation, December 1977.

hyperlinks to details associated with each change depicted in the diagram.

The subprocess for identifying likely contributing factors will be essentially the same as described for the previous process. Current reporting of contributing factors on crash reports has variable quality. Improved methods and training are needed to improve reliability of these reports. However, it is anticipated that the user will interact more intensively with the system, given the level of detail at which the analysis is being done, to alter conclusions that may be made from generic relationships that have been documented. As the system matures and includes elements of AI, the system should be able to more directly identify the likely relationships that apply to the specific site.

Preliminary Design Project (Reconstruction)

Once a designer embarks on specific design or redesign of a site, the particular geometric layouts can be significantly influenced by safety and other considerations than just those reflected in design policy. Constraints at the site (e.g., right-of-way) will greatly influence what or how something is done. Specific configurations or values for design elements, such as components of channelization, grades, and combinations of horizontal and vertical elements, may not be dictated, or even suggested by policy. However, the history of crash experience, traffic operations and control, and geometric changes at a site may suggest specific design strategies to employ within the overall design objectives of enhancing safety. Furthermore, analytical models and other design analysis tools may be employed to assess a proposed design. A diagram of the process appears as Figure H-5.

A designer, working on the preliminary design of a reconstruction site, will use the CADD/GIS to select the site. Most of the work will be performed in CADD, producing output in plan, profile, and three-dimensional views (including video segments and stills), and four-dimensional views (over time) using animation and, ultimately, virtual reality technology.

The designer will also be able to request a series of displays providing information about the site's history. Specifically, highly graphical summaries of crash experience will be displayed in a manner similar to that described for the problem identification activity. Similarly, displays of traffic control, vehicular volume, operational measures, and other design-related information about the current and historical physical and operational attributes of the site will be available to the user.

The system will facilitate the development of specific design objectives and the definition of associated MOEs to use in evaluating alternative concepts for a design. The selection of objectives and MOEs will depend in part on the project and the information available, both from data on the existing condition and from the design analysis routines.

The designer will be able to generate a set of design concepts employing one or more strategies suggested from the problem identification activity portrayed in the preceding process. Each of these design concepts may be tested further, using a suite of analysis tools to be provided by the system. The suite of tools is the central focus, as currently envisioned, of the IHSDM project. These include, but are not limited to

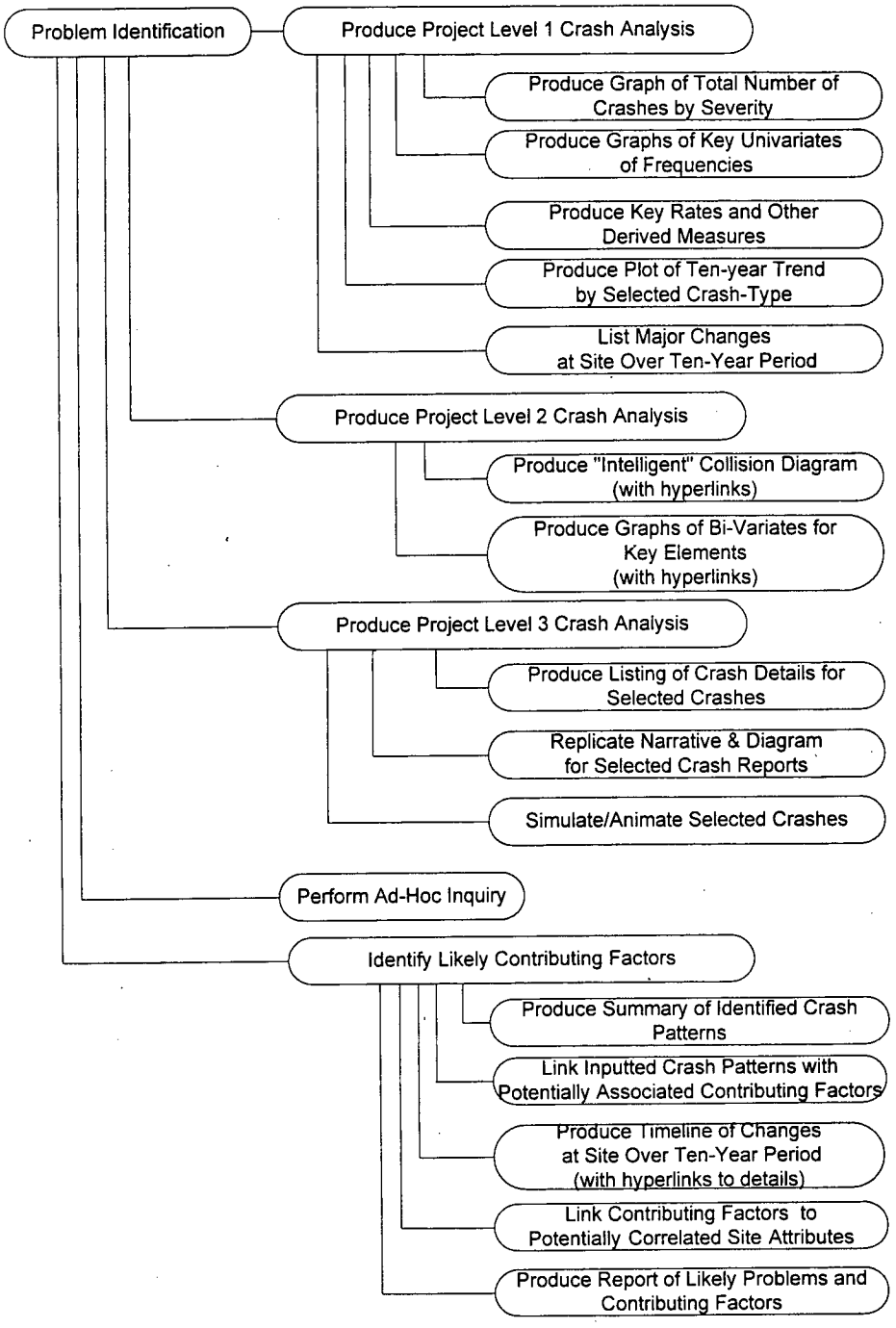

Figure H-4. High-level process dependency diagram for problem identification.

- A simulation of vehicle-driver dynamics to test the physical adequacy of the design (the IHSDM vehicle dynamics module). To the extent that the model can reflect information processing capabilities of the driver, as well as driver-control motor-skills, the model will also be useful to test areas such as information overload and design consistency (the IHSDM design consistency module).
- Analysis routines to assess positive guidance, information loading, and other measures reflecting principles of human factors in driving. Until human factors features are adequately represented in a simulation context, design analysis tools can be employed to independently analyze these.
- A design policy review element that can be used to identify where design policy has been violated (the IHSDM

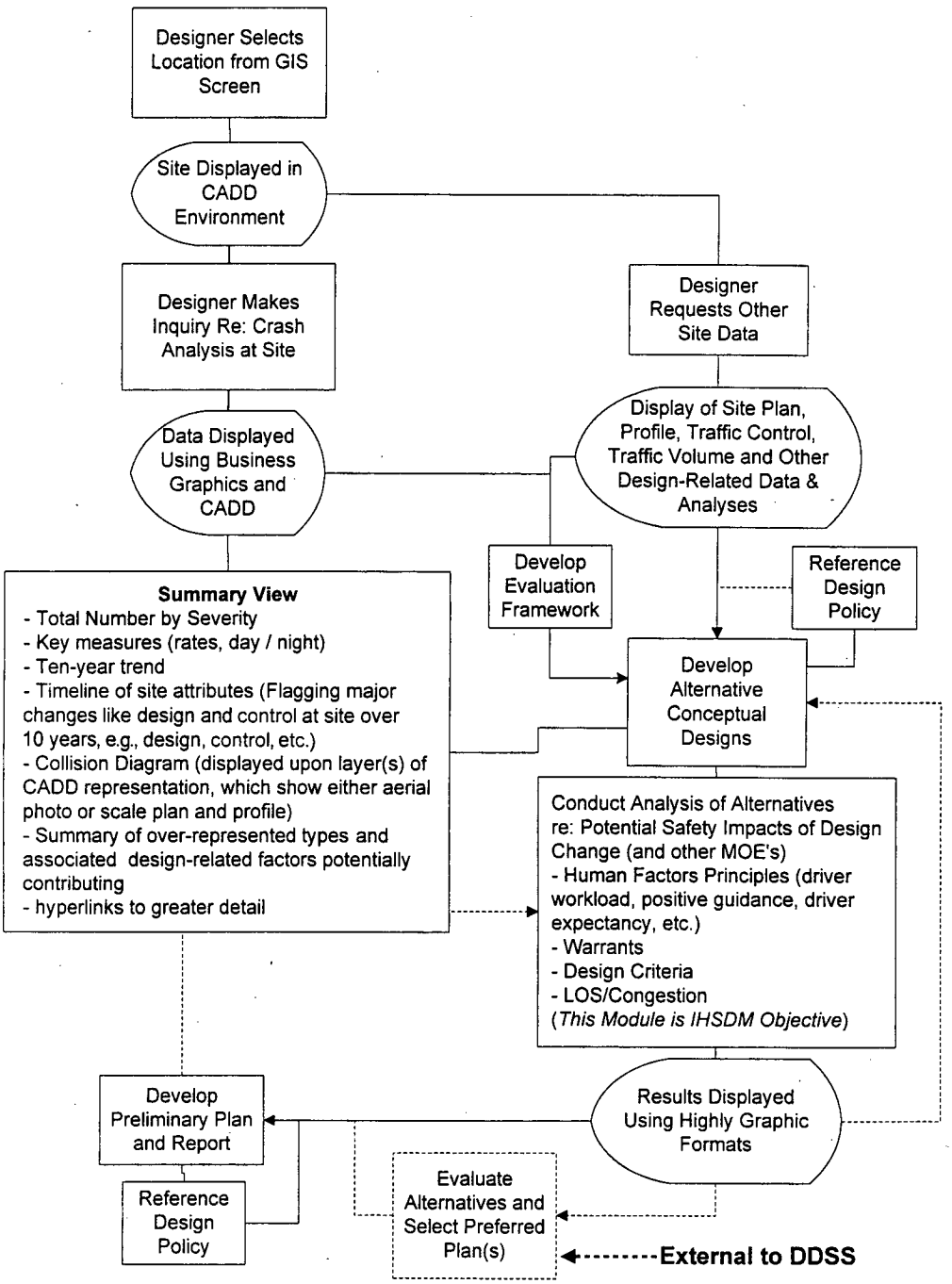

Figure H-5. Example system use preliminary design project.

policy review module). It can also be devised to assist in the analysis for a possible design exception.

- Models for predicting operational and safety impacts of a given design, which would be part of an ultimate implementation of the module (e.g., the IHSDM accident prediction module and the roadside safety module). However, concerns regarding statistical validity of safety-impact modeling require that the science will have to progress substantially before this aspect can be implemented. This system, as indicated above, will be designed to facilitate improvement of crash reduction estimates. In the meantime, users may continue to use crash-reduction factors of the type employed by several states. Whichever method is employed, it requires regular updating to reflect changing conditions.
- Economic analysis tools to translate the proposed design into terms allowing a cost-effectiveness analysis to be performed (the IHSDM cost-benefit module). Therefore,

means will be included for estimating project capital, maintenance, and operating costs, as well as for determining user costs.

The designer will be able to test each concept successively or in groups. The results will be displayed in a graphic manner, using information-visualization techniques, including overlays on the proposed design and existing conditions, to the appropriate extent.

It is likely that the assessment and selection of a recommended alternative will be done as an external step to this process (but still within the overall highway design process). Essentially all highway reconstruction projects of any substance must involve elected decisionmakers and the general public. This nontechnical audience is more often than not an appropriate target for the output from the above exercise. Perhaps one of the greatest benefits of the system is its ability to clearly demonstrate the quantitative trade-offs among various alternatives. To the extent that the designer can show with confidence all relevant inputs, and do so in a graphical method that is understandable to the public, the chances are greater that appropriate weight will be given to the best technical assessments of the alternatives.

A design concept report will be produced by the system for use in external assessments and to fulfill agency documentation requirements. It will present a set of alternative designs, accompanied by analytical assessments of each design. The results of the external assessment will be fed back into the preliminary design process, either as a request to generate further alternatives, a directive to stop or delay work on the project, or a basis for selecting one concept to recommend for development as the preliminary design for the site.

Ultimately, the designer will be working toward a recommended design, with the probability of documenting several other alternatives (including, as a minimum, a no-build alternative), and the reason for the preferred alternative. In many cases, there is an additional important step, external to this process. This involves further assessment of the proposed design relative to other possible investments in the transport system, a process referred to as *Major Investment Analysis*. Input for this may require further detailing of at least the recommended concept in the form of a preliminary design. The work for this will be based in the CADD system, with integrated access to design policy for reference. This can include a design policy review module of the type anticipated for the IHSDM, which can run in the background to immediately flag design elements that may violate policy and which can require either modifications or later approval of a design exception. A final report will result, documenting the recommended preliminary design and providing the background for its selection and development. This will be prepared with the assistance of the system's information presentation module.

Figure H-6 provides a high-level process-dependency diagram for the preliminary design application of the DDSS. The specific types of displays listed are oriented toward depicting the physical and operational features of the site, since it is assumed that the problem identification process will have been performed and that safety data will have been displayed and analyzed, as described previously. The evaluation process will be a highly interactive one, in which the designer specifies the objectives and measures. As the system matures, AI features will help the user arrive at these objectives. However, in its earlier implementation, the basic value of the system will be to create the cost-effectiveness framework within which the user performs the evaluation, thus providing consistency and discipline for the activity.

Once again, hyperlinks are used to assist the designer in navigating through the levels of detail available in the system. A summary of analysis results, usually in the form of an overlay on the CADD base for the plan or profile view, will use colors and other visual devices to highlight potential problems with the design. The user will be able to select a highlighted feature, and immediately the details on the problem identified will appear in a window. Output from design analyses will also be linked to the evaluation process to facilitate completion of that subprocess.

Analysis of a Design Exception

There are times when conditions suggest that one or more of the design standards might require compromising, usually by slightly exceeding or falling below the accepted maximum or minimum, respectively. This is often driven by economic, environmental, or political considerations, where unusual expense or environmental regulations may result in the need to implement a design to the full letter of policy. The exceptions being sought can range from major to minor.

In this activity, there is a need to replace opinion on potential impacts with as much soundly based impact prediction as possible. The DDSS is designed to support this objective. The process for this is shown in Figure H-7. The figure begins at a point in the process where conceptual alternatives are being developed. The top part of the figure, shown with dashed lines, follows the same process as described above for preliminary design.

However, because of the special nature of the analysis, there will be some variation from what has been previously described for a standard preliminary design process. This is shown in the lower part of the diagram, using solid lines.

Preliminary design work, using the proposed DDSS, will employ various design analysis tools, as described above. These tools will highlight the policy violations and provide predictions of impacts through models of the type being sought under the IHSDM program. However, the analyst wishing to pursue a design exception may want to go beyond the basic modeling, perhaps because of lack of confidence in the predictions. Accident prediction models usually have large confidence intervals around the estimates and have limited ranges of applicability, as determined by the data on which the relationships are based (i.e., extrapolation

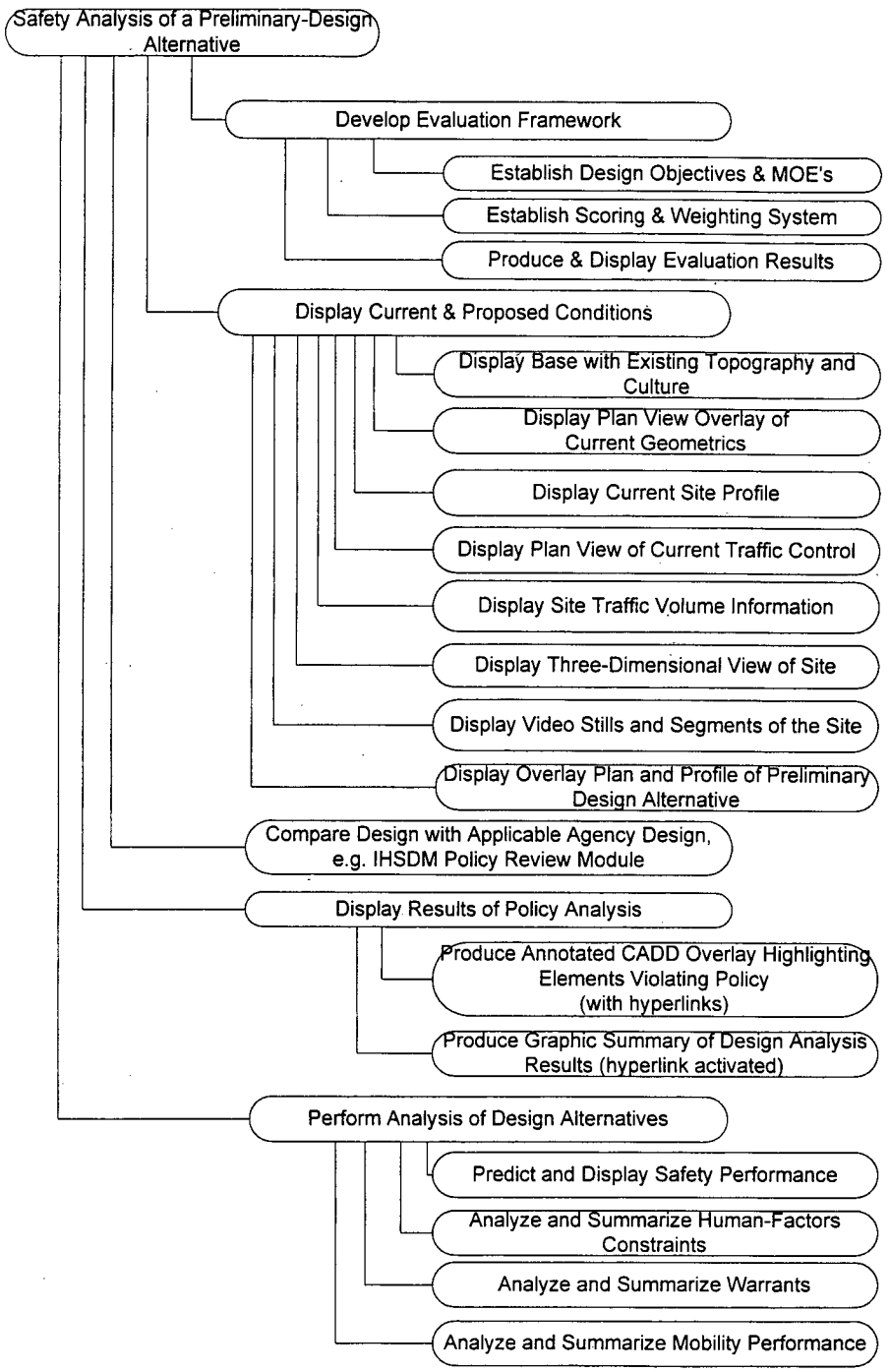

Figure H-6. High-level process dependency diagram for safety analysis during preliminary design.

may be required). Therefore, once design exceptions are identified, the designer may want to extract information from the DDSS by

- Identifying other sites with similar design and traffic attributes;
- Identifying, within this subgroup, which sites currently have similar deviations from design policy; and
- Identifying sites with the same or similar characteristics that were previously constructed with the design exception and have a reliable history to reference with respect to actual safety performance (in other words, a history file of design exceptions).

Having made the inquiry, the designer will then be presented with aggregate views of the selected sites, each of

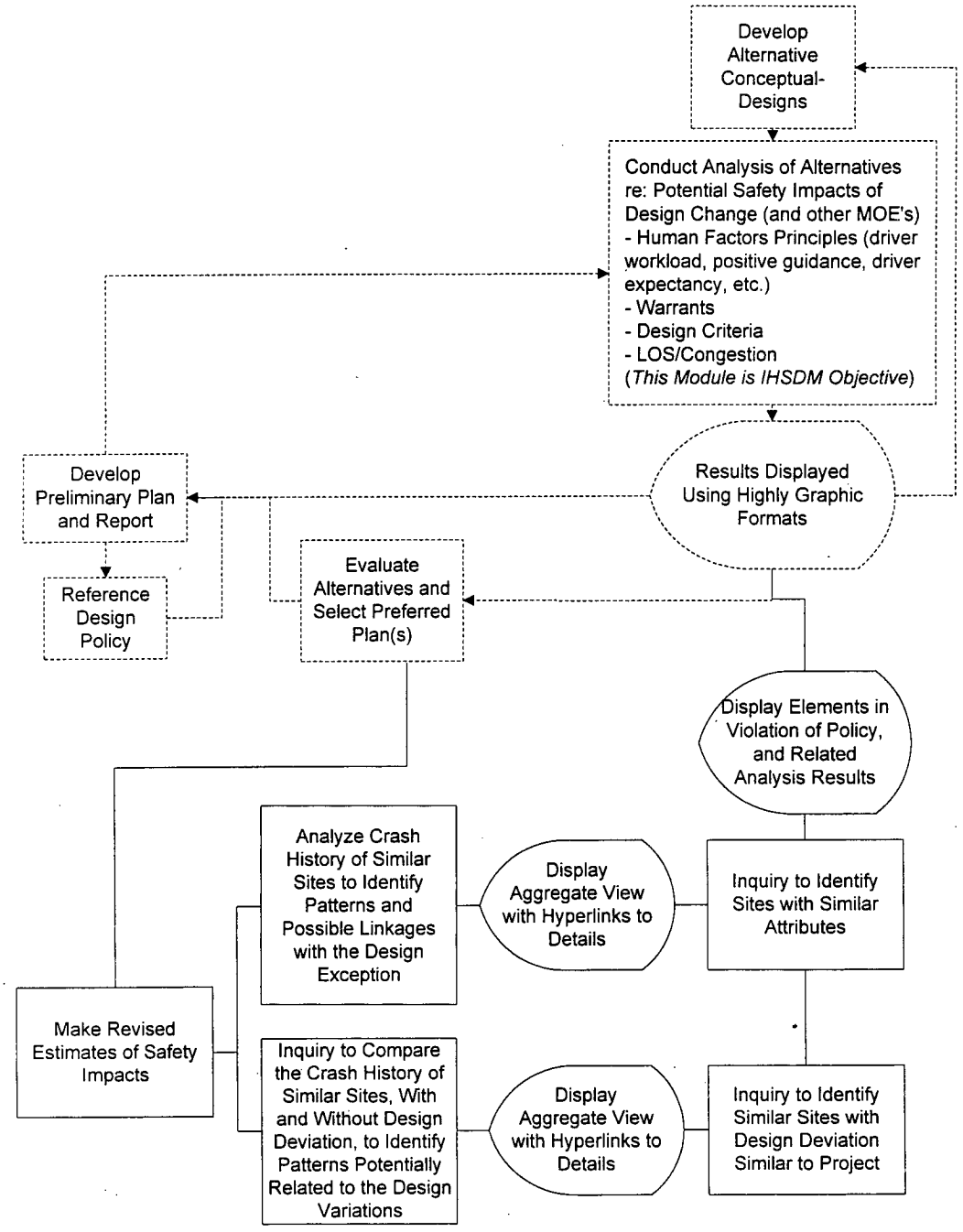

Figure H-7. Example system use safety impact of design exception.

which has hyperlinks to further detail. The designer may then examine the history of crashes for the subject site and the subset of similar sites that have been identified. Two types of analyses are indicated:

- Crash histories for all similar sites; and
- Separation of crash histories into two groups for comparison:
  - —Those that have similar types of design variations as being sought for the design exception and
  - —Those without design variations.

While the first type of analysis seeks to identify variations and possible correlations related to design features, when considering all similar sites, the latter seeks to achieve a simple comparison. However, it is not always possible to find many

comparable sites with design variations similar to the one being considered. Therefore, the second type of analysis will not always be feasible or may produce results with severely limited confidence.

This information may be combined to provide a basis for judgments on revising safety-impact estimates derived from the models. This exercise will also provide examples of other similar sites to which the decisionmaker may refer. Although prediction models may have sound scientific bases, decisionmakers generally find comfort, when being asked to grant exceptions, if they have examples of where similar variations exist and are operating satisfactorily.

The DDSS will be designed to provide the user with the appropriate search and summary capabilities. In its ultimate form, it is anticipated that AI features will guide the identification of the types of crashes likely to be impacted and arrive at the final estimate of impact. The revised estimate of impact will then be available to others who may be doing assessments of alternatives externally to this process. This would include, for example, investment decision making in the context of developing a construction program for the agency.

Figure H-8 is a high-level process dependency diagram for this activity. The subprocesses used for analyzing comparable sites are also applicable for analyzing comparable sites which also have similar design variances. Several subprocesses used for information display are the same as those to be used for other processes that have been described herein (e.g., site timeline, and intelligent collision diagrams).

Development or Refinement of Design Standards and Criteria

The following discussion illustrates the utility of a complete decision support system in a transportation agency's ongoing program of refining their design standards and criteria. Figure H-9 shows an example for system use in policy review and decision making.

Example: Design Standards for Superelevation on Highway Curves

Design of highway curves incorporates the use of superelevation to counterbalance forces on the driver and provide for a level of comfort. Superelevation design has remained essentially unchanged for over 50 years. Design policy as outlined in the AASHTO publications reflects a combination of basic physics, human factors research (much of which is over 30 years old), and assumptions (generally unverified) about safety implications.

An interesting facet of superelevation is the lack of consistent approach by design agencies in the use of maximum superelevation for a given combination of curvature and design speed. Some agencies employ policies that call for a maximum of 0.06; others 0.08; and still others 0.10.

This lack of consensus is interesting in that it has far-reaching implications on the resulting designs produced by each agency. What is also interesting is that each agency believes their policy is the "best" (i.e., "safest"). That different policies are employed suggests there is no evidence of a safety sensitivity that is strong enough to be accepted by all in the design profession.

Perhaps the greatest reason for the lack of safety knowledge about superelevation is the current status of relevant data, in terms of its completeness, accuracy, and reliability. Superelevation varies little relative to other physical dimensions of the highway, and there are many variables involved in investigating safety effects of superelevation. One would expect there to be little change in the basic approach to superelevation design until and unless the DDSS is in place to enable a rigorous study of this important design feature.

Looking ahead to the 21st century, consider that a nationally consistent DDSS exists, which provides reliable and complete data for the entire highway system. In addition, the state of technology is such that obtaining dynamic data in real time is a relatively simple and inexpensive exercise. With this being the case, an agency decides to undertake a study of their current policy on superelevation design for highway curves.

Study Requirements

The study is intended to establish whether there is any safety advantage (or disadvantage) to a design policy of 0.06 versus 0.10. A research study must identify a sufficient number of curves designed to each policy. Controls must be established for the full range of other geometric features so that the effects of superelevation can be highlighted and separated from other effects. Thus, the study requires a wealth of detailed and accurate data for any site.

These data must include the horizontal and vertical alignment, roadside, cross section, pavement condition, presence of special features such as bridges, intersections, and traffic control (including signing and marking).

The study also requires a complete and accurate record of prior history of operations, including traffic volume, traffic distribution, and speed distribution. Finally, the study requires that recorded crashes be accurately matched to subject curve sites and that the characteristics of each crash be clear and accurate. This will enable sorting by type and will provide an understanding of driver and occupant conditions (including age, driving experience, injuries, etc.).

Other nonhighway-related data are also necessary to ensure good study design and accurate findings. Knowledge about weather conditions is desirable for each site, including an estimate or measure of the time over each year that the pavement was wet or icy.

For this study, it is necessary to compare two different jurisdictions (probably states) that use different policies. Therefore, it is essential to success of the study that the same data be available at the same level of completeness and accuracy for the different agencies or jurisdictions. There must also be assurance that crash reporting is consistent.

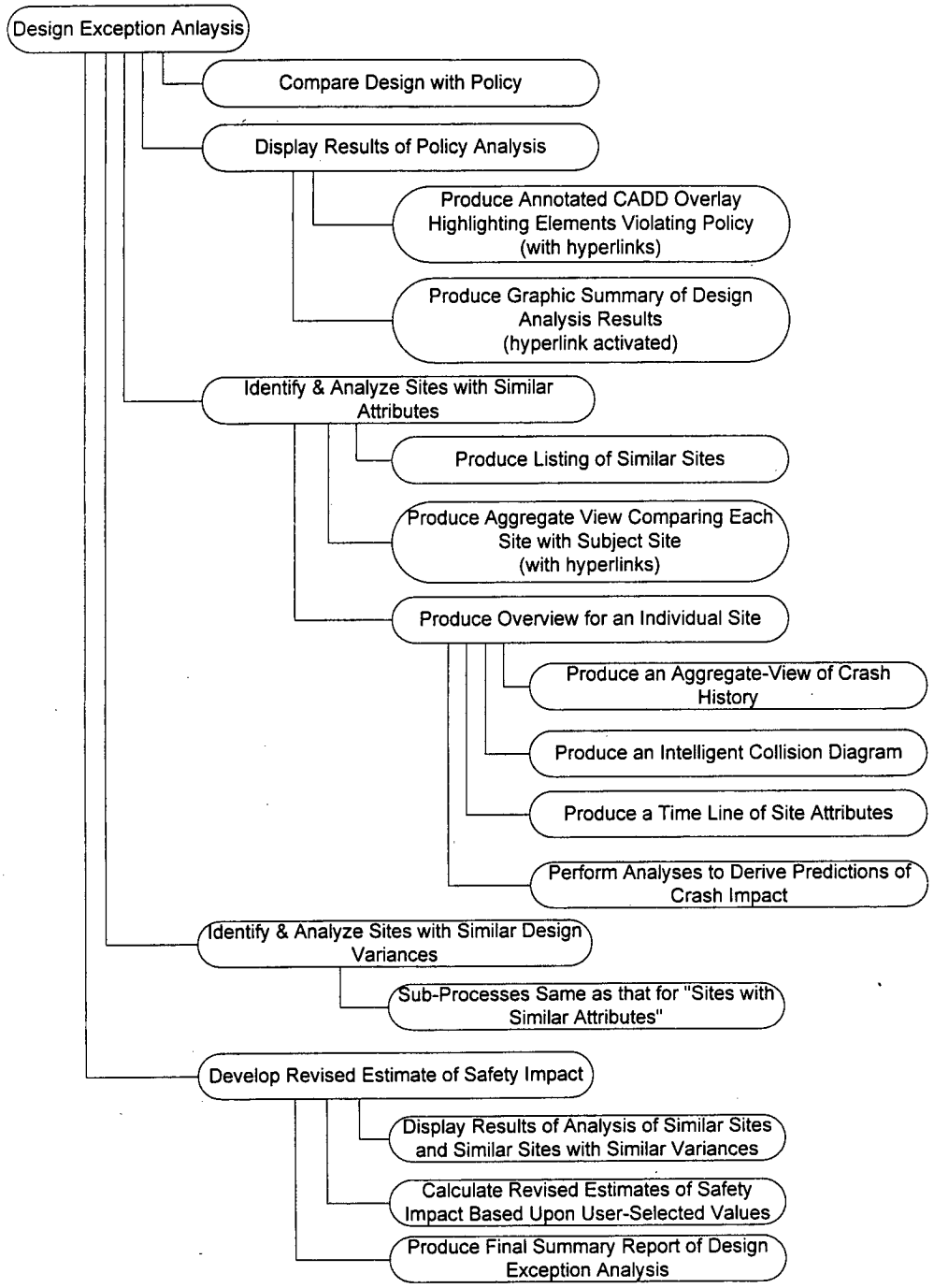

Figure H-8. High-level process dependency diagram for safety impact of design exception.

Study Process Using DDSS

Figure H-10 shows the high-level dependency diagram for review and decision making. The research engineer first performs a literature review, accessing previous reports, studies, etc., through the Internet. She is quickly able to pull up, review, and document the state of knowledge to date in a matter of hours without leaving the office. From the research, she learns about the expected relative effect of superelevation on safety and learns about the many confounding factors that will need to be studied. Also via the Internet, she conducts a survey of counterparts in highway research worldwide to see if anyone is undertaking a similar study. She also uses the Internet to survey the state-of-the art of superelevation design practice. Her research also leads to an understanding of the sample size and study design requirements for her project.

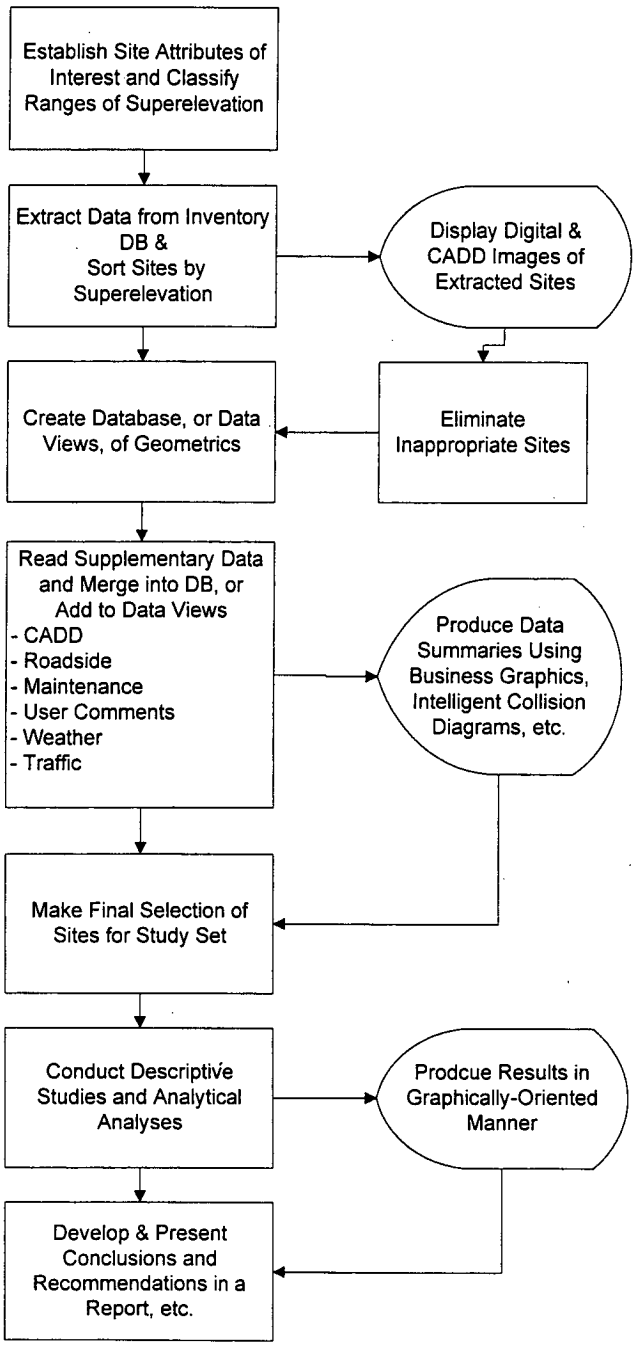

Figure H-9. Example system use for policy review and decision-making.

Her next step is to design her experiment. She needs to develop a large database of highway curves from two agencies, representing the two different superelevation policies. Her data set must be constructed to control for or enable measurement of the effects of all other geometric features.

She accesses the data warehouse that holds all geometric data for her state. Using standard sorting programs on her networked computer, she builds a file of potential curve sites with the range of desired characteristics. These are described by their x,y,z coordinates on that state's system. Certain sites include questionable data. To be conservative, she believes it best to check visually a sample of the sites. She accesses the computerized video inventory of selected sites at her desk. This file, generated biannually, provides a picture of the site in question.

Characterizing the roadside for each site is critical to her. She is able to translate each site's roadside conditions (based on offset, type, length, and other variables) to a probability function using recently completed roadside research that also used the improved decision support system. This function will be a key variable of interest in her experiment.

For very detailed data such as superelevation transitions, she must access the design drawings of the site. She calls up the CAD files for each curve, noting the date of construction and pulling off design data from the CAD files for each site as necessary. She also accesses the computerized timeline for each site. The timeline identifies maintenance activities, with direct linkages to computerized maintenance files. Here, she is interested in pavement patching, resurfacing, or similar activity that may have occurred during the desired study period. Finally, she accesses the state's pavement management system by computer. This provides a history of pavement condition for each curve, which will be used to control the database, or as a variable of interest.

The above exercise did not require her to leave the office. All data were available through a readily accessible data warehouse. Once the study design was completed, the effort to build, interrogate, and supplement her geometric database took about 1 month.

The research engineer next focuses on characterizing the necessary operational characteristics of each site. Ten years ago, her state implemented a comprehensive program of traffic volume and speed data collection. Data have been gathered using a combination of in-place roadway sensors that report directly to the central office database and satellite data collection. These data are available for most of the sites in her database. They are saved on an annual basis. For missing or incomplete data, she is able to call up the traffic section, and schedule a counting program using her agency's share of the multijurisdictional traffic satellite.

Again, she accesses the timeline for each site, identifying measures of annual traffic volume, heavy vehicle distribution, and measures of speed distribution. Sites with rapidly changing traffic volumes, unusual patterns of traffic, etc., are investigated further. A site's timeline provides insights. For example, in some cases a local detour associated with a nearby construction project 3 years ago affected traffic patterns. The research engineer makes decisions about screening out some sites based on this analysis.

The last step in the process is the building of the database of crashes. The research engineer's focus is on matching crashes for the period of analysis to each site. Moreover, she needs to be able to differentiate those crashes that might reasonably relate to superelevation.

She accesses the data warehouse with the coordinates of each site's curves, using a matching program developed by the state's information system staff. Direct data linkages to the statewide database of crashes results in a complete file.

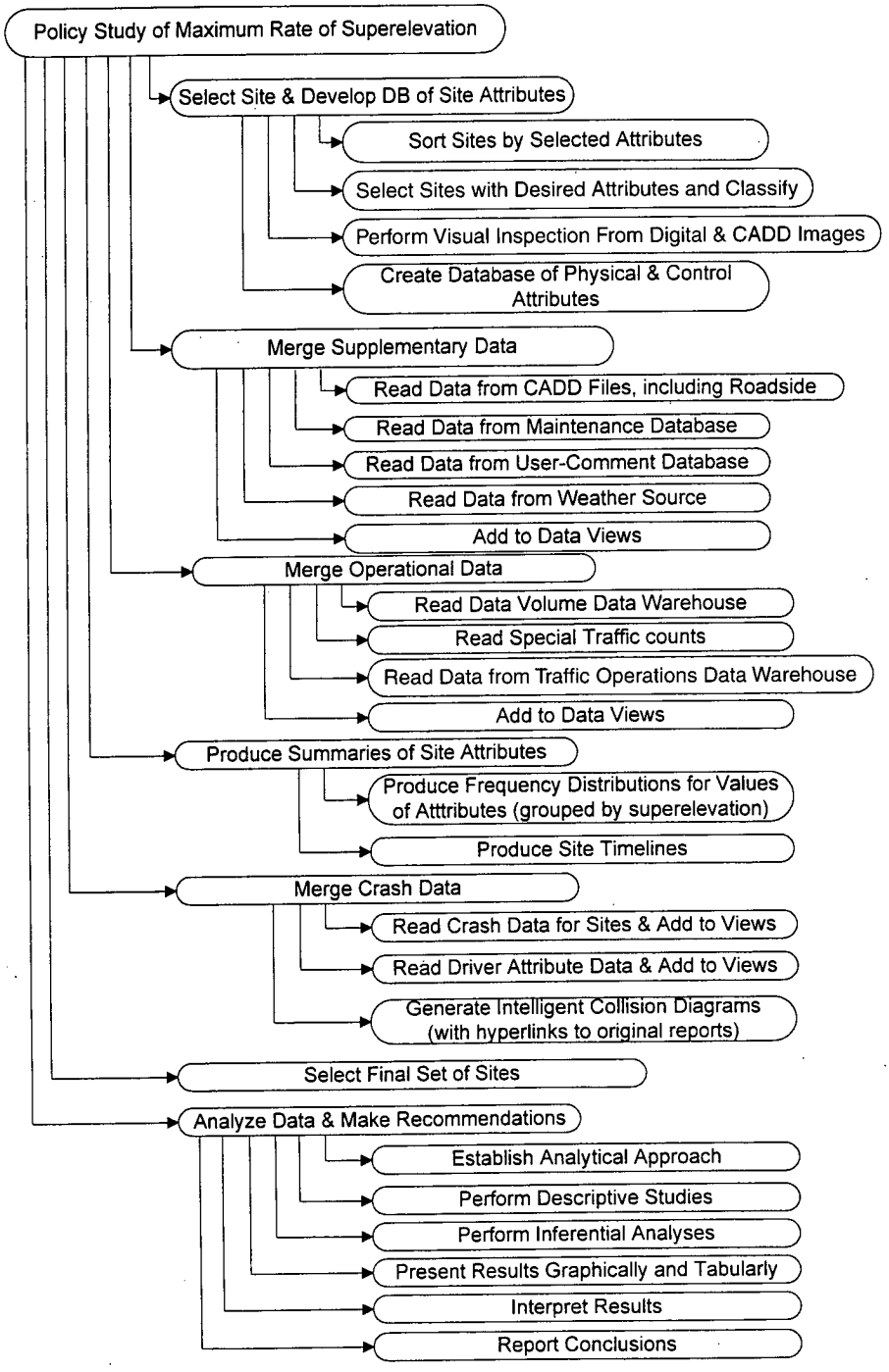

Figure H-10. High-level process dependency diagram for policy review and decision-making.

She uses an expert system program to help sort and identify crashes by type that could be related to curve tracking, speed, and possibly superelevation. She uses another expert system program to test the characteristics of reported crashes at each site, looking for unusual patterns or frequencies of crashes. The program displays the data in understandable formats using business graphics to highlight possible anomalies for further study.

Those sites with unusual crash characteristics are investigated further. She is able via data hyperlinks to call up on her computer selected hard copy crash reports, which she reviews. With this detailed information, she is able to make better judgments about applicability of sites, inclusion of accidents, etc. Some sites are screened out of the study, as are some crashes.

She is able to verify and refine characterization of driver injuries by accessing a central database of hospital admissions

and patient conditions. She is also able to develop a file of driver characteristics from the state's licensing database, also accessible to her through linkages. These data enable her to identify and/or control for potential biases. She also is able to access the National Weather Service computerized records. These are searched to develop estimates for each site of the days during the year when pavement at each site was wet, snowy, or icy. (If necessary, she can back-check the hard copy accident reports for any given day to verify the accuracy of the weather data.)

Once this task is completed, she has a complete database of relevant crashes matched to each site. The data describe detailed, accurate, and complete multiyear records of geometric conditions, speeds, volumes, and traffic control. With this information, she is able to complete the necessary sophisticated statistical analyses that will address the sensitivities of superelevation.

The above exercise, including study design, database building and checking, and analysis could be completed within a 6-month time period. Her analysis, report writing, and discussions with senior management could take another 6 months. At the end of this period, she can make a recommendation regarding a new, revised design criterion for superelevation. It is reviewed, approved, and formally adopted by the agency. The revised policy is published on the agency's intranet, which updates agency design and administrative policies weekly. The research engineer is asked to put together a short presentation on the new policy, explaining the research findings that led to the change. This is done using standard business graphics and other support programs and is broadcast on the agency's video conferencing network.

Data Needs

The system defined and the example applications described above require a fairly comprehensive set of data to generate the desired information. Figure H-11 is a diagram of the safety data desired for the system. These data are divided into four main categories:

- Crashes,
- Maintenance,
- Site experience, and
- Highway.

Each of these is further subdivided into classes of data. A relational database design requires that the data be linked

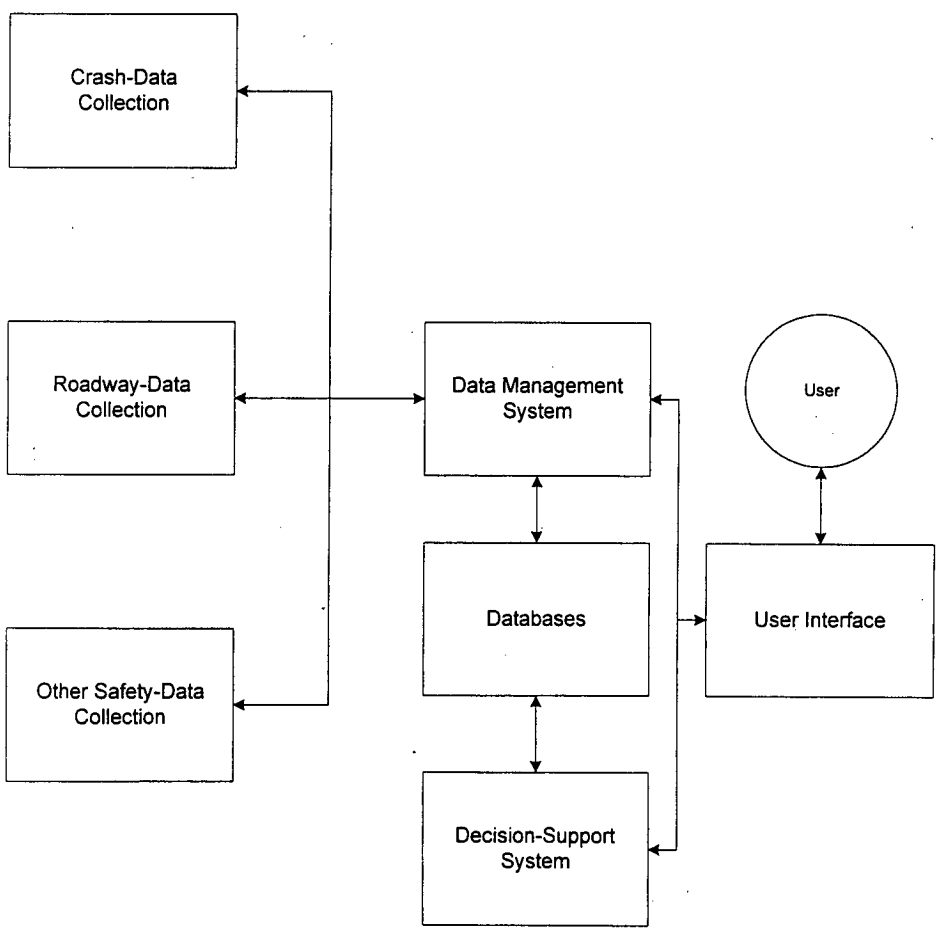

Figure H-11. General concept system to support safe design.

where appropriate so relationships can be established. The database for the DDSS will primarily link the data through the associated location code. Location coding will be determined on the basis of geocoding, with equivalency tables being developed to convert from other existing systems, until the entire system is on a geocode basis.

Time would be a secondary basis for linkage. Time is also included because crashes are events (i.e., time related), and the condition of the highway changes over time, so any particular attribute exists for a given period of time. This feature of the database is shown in the entity-relationship diagram in Figure H-12.

Specific types of data that are desired within each class are defined in the table in Appendix D, which serves as an initial data dictionary for the system. An extensive discussion of issues associated with the collection and use of safety data has been included in reports from other tasks and will not be repeated here.

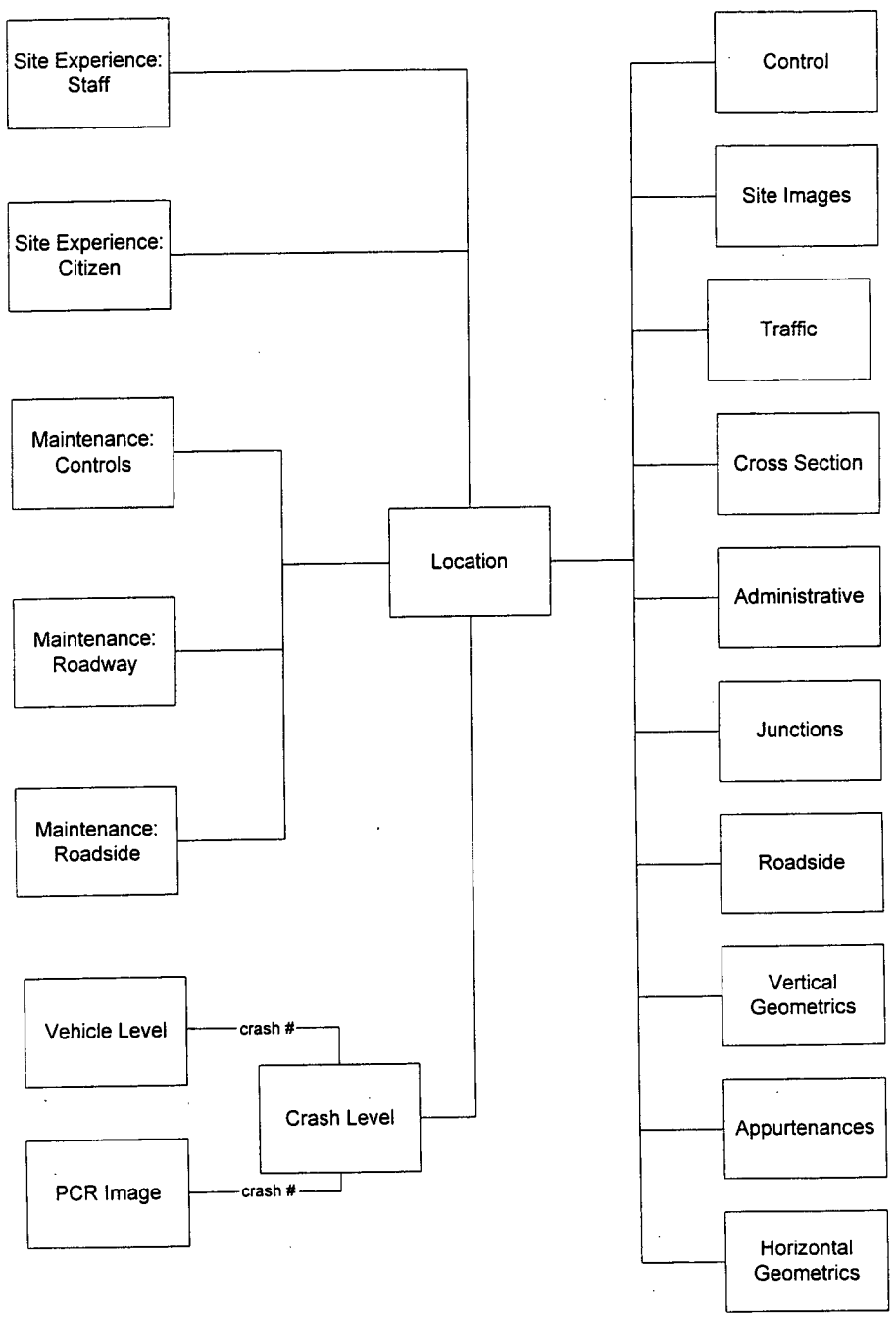

Figure H-12. Safety-data entity-relationship diagram.

Perhaps the greatest difficulty in obtaining needed data is the disbursement of responsibilities and even databases that contain the requisite data. This disbursement grew, in part, out of different sources from which data evolved with differing objectives, criticality of collection, and responsibilities of the agencies reporting them. Most notable are the differences between crash data and roadway data. For crash data, the primary collector has been the police who have a responsibility for enforcing the law. Their objective in obtaining data from crashes remains to meet case obligations, both criminal and civil, that may arise from the crash. Most importantly, where the crash is minor and the outcome likely to be simply an insurance matter between the involved persons, the police may simply be acting as a source of verification rather than as a crash reporter.

Reflected most notably is the differentiation in degree of importance given location of the crash. For the police, unless a criminal case is forthcoming (e.g., reckless homicide), they are more concerned with ensuring that no confusion can arise among cases representing different crashes at the same location. Because few locations have multiple crashes even in one day, the approximate location, date, and time are sufficient to identify the crash. On the other hand, precision in location can be critical to engineering needs. Even the difference of 100 meters can make the difference between highlighting a potential hazard (e.g., sight distance at a vertical curve) and a potential "chance" event. For the police, each crash is an independent occurrence; for the engineer, it is the accumulation of crashes at a given site that is of interest.

Conversely, the collector of roadway data, which is usually the highway agency, has a direct stake in those data collected. They will be of value in the design, construction, and maintenance of roadway. The data also have become increasingly important in protection from tort actions. To ask the highway department to collect data regarding traffic or criminal violations on their roadway would result in such data receiving a relatively low priority given the limited direct value to that roadway agency.

Yet, the crash data are important in the safe design of roadways. In many cases, the roadway data may be important in relationship to law enforcement (e.g., poorly timed traffic signals which might encourage traffic violations). However, because the police have not been trained to use crash data in a larger context (e.g., traffic safety which relates the motorist and roadway as a single entity), they will not have a stake in collecting data that can be used to help improve design.

Ultimately, the collection of valid data, especially about location and sequence of events, which is so important to safety in design will have to depend on sources other than the police. One of the most promising is the use of "black boxes" on vehicles which, when coupled with GPS positioning data, could provide many of the data now lacking on crash reports.

Simply having the data available at the same physical location does not necessarily mean that they are shared easily. Some states have enhanced their systems so that both the crash and roadway data are available to both sets of users interested in the information. However, linking systems is costly, especially if the databases are residing on different platforms under different operating systems and database management systems. Obtaining the necessary funds in the current economic climate must clearly be accompanied by offsetting benefits to link the databases.

The one category of data that has been overlooked by most agencies has been that of site experience other than crashes. The most useful data probably are those in the form of complaints and comments from the motoring public and highway maintenance personnel. They can provide insight into situations that may be unsafe but that have not led to crashes. Using these data to supplement crash data may assist in correcting design problems before they become more costly in terms of crashes or even possibly as tort actions.

APPENDIX I

DESIGN SCENARIOS FOR ASSESSING BENEFITS

1. Reconstruction of Four-Lane Urban Arterial Street

Main Street through the town of Springfield requires reconstruction. A combination of deteriorating pavement, recurring congestion, and development has resulted in complaints to the Department of Transportation. The town board and mayor support the concept of reconstruction.

The existing street is a four-lane undivided arterial carrying 25,000 vehicles per day. A 5-mi-long section of the street passes through a commercial district, with retail stores, fast food restaurants, and other driveway activity. The right-of-way is 24 m (80 ft). There are signalized intersections every ¼ mi. The posted speed limit is 35 mph.

The combination of high traffic volumes and driveways with no left-turn protection creates serious problems for drivers. In recent years, there has been a noticeable increase in the number of left-turning and rear-end conflicts and crashes.

Joe Smith of the district office of the State DOT is assigned the task of developing a reconstruction plan for Main Street. (The District office is in a town 40 mi away.) He knows that he will need to not only develop an operationally safe plan, but that it must be acceptable to the Town, its residents, and the Main Street merchants.

Joe's staff begins working with him to develop a plan. Among the early tasks is establishment of a complete understanding of the safety problems. This requires acquisition of reported crash data, traffic volume data, and data describing the design characteristics, traffic control, and other features of the existing road.

The State DOT's crash data are maintained at the Central Office. Joe's staff must prepare a written request for the most current 3 years' worth of data, specifying the mileposts of the road in question. Recent downsizing of the DOT has affected the Central Office staff. They indicate they have a 3-week backlog of similar requests. Moreover, the most recent available data is 18 months old. Data for the past year are still being entered by data processing staff. Their practice is to make a given year's data available by October of the next year.

After waiting 3 weeks, a large computer output arrives on Joe's desk. It is accompanied by standard tables summarizing the types of crashes, severity, day versus night, and so forth. Joe's staff are familiar with the standard output, and using code books, they begin reviewing the data. One of them notices a mistake in a milepost. They must call the Central Office to get the correct data. This arrives 1 week later.

While the above is going on, other members of Joe's staff are collecting traffic volume data from the Planning Section. They learn that there is a 3-year-old ADT count on file in the middle of the section. However, no turning movement data are available for the 15 signalized intersections along the route. Staff must be sent to the field to collect such data, resulting in the expenditure of more than 350 hours of technician time (counting travel to the site and back).

Once the data are available, staff compute crash rates for each section of the corridor. Certain sections appear to be high compared with others. Staff ask Joe for direction. He calls Central Office, who send him an annual report of average crash rates for 2-lane, 4-lane, and multilane divided highways in urban areas statewide. The Central Office suggests Joe use these as a reference.

The DOT staff know what the "best solution" to the corridor is. Their design manual notes that a 4-lane, divided cross section within 100 ft of right-of-way is called for. Providing a median and better controlling left turns is viewed as optimal. However, Joe has been in similar situations before. He knows that the Town and particularly the merchants will not like losing cross median access. Also, acquiring an additional 20 f of right-of-way will be difficult and costly. Some building acquisitions will be necessary. For these reasons, Joe counsels his staff that they should be prepared to develop some alternatives, including two-way left turn lanes (TWLTLs), narrow lane widths, or a combination of these.

As work proceeds and interaction with the mayor, merchants, and residents occurs, the project becomes controversial. Joe and his staff insist that the raised median alternative is "safer" than the others. The mayor demands to know what "safer" means. Joe is scheduled to give a presentation to the Town Board in 2 days, at which time he is expected to present the results of all analyses and make the DOT's recommendations. Joe asks his staff to help him collect any information they can find that addresses the safety of different cross sections. One staff member recalls reading about a project in *ITE Magazine*. He finds the issue and passes it along to Joe. It is somewhat similar, but is from another state. Moreover, the design conditions are not exactly the same. Another staff member does a literature search and uncovers a few research studies that provide general models describing expected accident rates for TWLTL cross sections. No data were found, however, describing the safety effects of narrower lanes on arterials. A third staff member, who recently transferred from another district, recalls a very similar project from the state about 5 years ago. He calls a former co-worker, who confirms that the project is similar, the new design "is working very well," and that everyone is happy with it.

Unfortunately, when asked about details of the safety effectiveness, the co-worker says they hadn't performed any "after" studies. The staff member frantically calls Central Office to see if he can get before and after data for the comparable project. He is told that (1) it will take 3 weeks to get the data to him and (2) in any event, the before data would not be available, as they do not retain crash data that is more than 5 years old.

Joe knows that the public understands diagrams better than tables. He requests his staff to prepare a collision diagram illustrating the accident problems along one stretch of the road. Two staff members work overtime to get the plot completed in time for Joe's presentation.

Joe goes to the meeting with the information in hand. The design drawings illustrate the specific right-of-way impacts and access impacts of the DOT's proposed plan. He tries to convince the Town to support the DOT. His lack of substantive safety information to argue for a raised, full width median design, however, results in the Town's vocal opposition.

Benefits of integrated system of safety data. A fully operational system of safety and other data would have appreciably affected the performance of Joe's project. Real-time, interactive capability of accessing the crash records would have saved at least 1 month of delay. The use of traffic volume data from computer traffic control systems would have eliminated the need to expend resources on manual counts and would have improved the quality of the data.

A system in place with more complete traffic, safety, and geometric data would have enabled the State DOT to have more complete measures of safety differences for the possible alternatives. The effect of various combinations of geometric features would be better modeled, allowing Joe to furnish estimates of differences with more confidence.

Automatic plotting capability for collision diagrams would save staff time and enable staff to respond quickly to requests for information.

A computerized history file of all previous projects, including geometric, volume, and crash data would provide Joe's staff with a complete record of the State's experience on similar work. Moreover, a history file of crashes would enable a rapid analysis of the before and after experience for relevant projects.

Having the ability to quickly, confidently, and accurately address concerns about safety might or might not have made the difference in the Town's perceptions. However, it would have maximized the chances that the Town, and, indeed the DOT staff, would have assessed the expected safety experience with the same weight as other factors such as right-of-way, access, and construction costs.

Summary. The above scenario illustrates common problems associated with controversial urban arterial projects. *Inaccessible safety and volume data* require the expenditure of considerable time and resources. *Lack of interaction* with the crash data create quality control problems and delays. *Insufficient safety performance measures* inhibit the ability of staff to make good trade-off judgments and to provide with confidence the projected or expected effectiveness of the proposed alternatives. *Lack of history data* prevent staff from applying knowledge of previous similar efforts in their state.

An improved system would save time, improve staff efficiency, and reduce the costs of alternatives development. It would also improve the quality of the safety information, and, just as important, the perception of the quality and importance of safety data by the public and outside stakeholders.

In the absence of firm safety estimates, the designer and public are left with judgment and adherence to design standards as safety measures. Faced with well-documented adverse effects of the full standard design, the Town and general public downplay the safety issue and oppose the solution that the DOT believes is the best.

2. Reconstruction of Two-Lane Rural Highway

US 99 is a two-lane highway carrying roughly 4,500 vehicles per day through the foothills of a western state. The road was originally designed and constructed more than 50 years ago. Its pavement has worn out, and it requires complete reconstruction. Mary Jones, design squad leader in the DOT District office, has been assigned the job of developing final construction plans for a 22-mile section of US 99.

The planning section provides Mary with traffic volume and vehicle distribution data for the existing and design years. Her capacity analyses indicate that the road need not be widened, but consideration of passing lanes is warranted in a few locations.

She conducts a complete review of the existing geometric alignment and cross section of the road. This is based on both field reviews and reviews of old sets of as-built design drawings. Given its age, she discovers that many sections of the highway are substantially substandard with respect to existing design criteria. Moreover, even a cursory review of the alignment and terrain suggests to her that bringing the highway up to full standards will require substantial construction. It appears that many "design exceptions" may have to be sought.

Mary decides that a review of safety information may provide insights regarding where design exceptions may be acceptable. She requests the latest 3 years' worth of accident data for the 22-mile section.

The Central office staff send her a printout of crash data for the last 3 years. They also furnish her with tables describing average accident rates for two-lane rural highways in her state and a listing of high accident sites as identified by their formulas for sections within her 22-mile study area.

Mary reviews the printout. She discovers that one section in particular appears to be a problem. There are apparently numer-

ous run-off-road crashes resulting in injuries. She reviews the plans and visits the site, but can find no unusual geometric problems. She further examines the printouts and finds that the recorded milepost information does not correspond with descriptions of the highway geometry at the reported location. Mary decides she would like to see the hardcopy crash reports for the section to understand better what is going on. She calls Central Office and requests copies of the accident reports. She is told they do not maintain these and is directed to the County Sheriff, who was responsible for the original data. A call to the Sheriff results in her sending a staff person to their offices, where the better part of a day is spent sorting through old files to find the hardcopy reports.

Once she has the hardcopy reports in hand, she is surprised to find that there are many discrepancies in the data. Some reports are for a section of highway 10 miles down the road. In other cases, the officer's description of the location does not make sense. She does, however, find much useful information. In particular, the narratives and sketches drawn on some of the reports provide a clear picture of a recurring skidding problem. (Mary notes, however, that not all the reports are prepared to the same standard of care and detail.)

At another location, she finds no record of any crashes in the past 3 years. In her field review, however, she distinctly remembers seeing skid marks and damaged guardrail along the outside of a curve.

Along one 3-mi segment of the highway, the vertical alignment is particularly substandard. The effective design speed of the vertical curves is only 45 mph. The computer printout shows that this segment has a crash rate about 20 percent higher than the average rate for the state, but Mary is not sure how to interpret this. Because she does not trust the location data for the crashes, she cannot link with confidence the crashes with the locations of limited sight distance. Her judgment tells her that the alignment is probably acceptable given the volume and rate (Mary has read TRB publications that discussed the cost and safety effectiveness of AASHTO vertical curve criteria), but the overall section rate is too high to dismiss. In any event, given the rate, she probably would not be able to convince the FHWA of the acceptability of a design exception.

After completing her field studies and reviews of the hardcopy reports, Mary's confidence in all the crash data is shaken. She is not sure she should rely on any of the other data without checking hard copies. Her supervisor, however, does not feel it is worth the time or effort to verify the data for what should be a "routine" project. She is also reluctant to go with her judgment about retaining substandard alignment in the final plans. Her senior co-workers have warned her about having to go to court to defend substandard designs.

Mary begins preparation of plan and profile for the highway. Her design work confirms her earlier fears that there will be costly and difficult construction required to bring the alignment to standards. Against her better judgment, she proceeds. Her final design is well received by the District. The 22-mi section is constructed for $50 million; Mary believes it could have been closer to $40 million had she had the confidence and information to design to different standards or to pursue design exceptions.

Benefits of improved safety information system. Improved safety information would help designers provide cost-effective designs. More accessible data would have allowed Mary to spend more time on other productive activities. This includes the ability to interactively access the state crash database and the ability to plot and/or summarize site-specific collision diagrams, tables, and crash summaries.

Better quality of data, in particular location data, would have improved Mary's confidence in her understanding of the actual existing safety conditions. This might have led her to propose a more cost-effective design.

A high-quality history file of design exceptions, with accompanying post construction reviews of the safety, would have helped Mary to decide whether certain design exceptions would have an acceptable safety record.

Mary has very high confidence in her understanding of the design requirements and construction costs associated with a full standard design. She also would have high confidence in the savings that could accrue if certain design exceptions were proposed. She does not have sufficient confidence in the quality of the crash data to convince herself that anything less than a full standard reconstruction is warranted. The result is a substantially more costly project than could have been provided, with no apparent benefit.

Summary. The above scenario illustrates the benefits of a system that provides *high-quality location crash data.* Also, *inaccessible data* force the unnecessary expenditure of resources to learn about safety. Finally, *lack of history data* for previous projects prevents an agency from taking advantage of lessons learned on previous projects. This is particularly important for reconstruction projects in which design exceptions are common.

3. High Accident Site Program Development and Implementation

Ron Jones was just appointed to lead one state's program of high accident site identification. His predecessor just took early retirement and is now working for a consultant. Ron will work closely with the traffic and safety division in Central Office, who are responsible for maintaining crash data and traffic volume data.

The system in place produces estimates of average rates and 95th percentile confidence intervals for five basic types of highways in the state—two-lane rural, four-lane divided expressway (rural), urban divided arterial, urban undivided arterial, and urban freeway. The statistics are used to identify locations on the system that exhibit unusually high patterns of crashes.

Ron recently attended a safety conference at which he learned much about the complexities of relationships between crashes and highway geometry. When he returned to the office, he convened a meeting with staff to discuss how they could improve their identification of high accident locations. The discussion included traffic, safety, design, and planning staff.

The staff reached a consensus that they could do a better job if they had better data to work with. The safety staff suggested trying to use the state's geometric data files to better segment and categorize highway types. When they discussed this idea further, however, significant problems were quickly evident. The geometric data file described location information using a different milepost reference system from the accident records. There was a coding manual that had been developed to help make the conversion, but it was not up to date. The geometric data file contained only information about cross section, intersection location, and speed limit and a general categorization for horizontal alignment. There were no data describing the roadside condition, location and design characteristics of barriers, vertical alignment (including vertical curvature), or intersection channelization.

Similar problems were evident when the traffic data were discussed. The state had few good records describing intersection turning volumes at even major intersections. Locations where permanent count stations were maintained were too far apart in many locations to meet the needs of the safety analyses.

Everyone agreed that the state could do a better job with more and higher quality data, but under the current system it was not possible.

Ron then suggested that perhaps they should focus on measuring how effective their current methods were. He asked how the staff knew what effectiveness their program had. One of the senior engineers referred Ron to the state design manual, which included a table showing the expected effectiveness of treatments for high accident locations. It included geometric, cross section, guardrail, signing, lighting and other treatments, with percent accident reduction factors. The staff explained that each project was assessed using this table. Priorities for implementation were based on the cost-effectiveness of each proposal.

Ron was puzzled. How, he asked, do we know that each site performs as expected? The staff then related anecdotal evidence, discussing recent project successes. Everyone "knew" that what they were doing "worked."

Ron decided to do an independent post mortem of recent high accident project improvements. He identified a sample of 50 projects completed over the past 3 years. He assigned a staff engineer to research the history of each project, identifying the pre-construction accident history and the expected effectiveness. The staff engineer spent the next 2 weeks in the basement of the DOT offices, going through old project files. She was able to find 42 project reports—for the other 8, the files were missing.

The staff engineer spent another week researching construction drawings and records. She was trying to find actual construction bid information and dates of construction.

Ron then requested that the safety staff research the accident experience at each location since the improvements. This turned out to be a time-consuming task as well. At many of the sites, the milepost references from the original engineering report had changed because of recent construction. Staff had to carefully construct the same segment definitions to provide accurate comparisons. Some of the projects were more than 8 years old since the original engineering. Traffic volumes had changed significantly. Ron requested the traffic section perform special counts to update the data. The work order was placed. He was informed that they should have the counts in 2 months.

Once the analyses were complete, the staff discovered that, of the 42 sites, there was no apparent improvement in 7 of them. At another 15, the improvement was minor, and, as Ron suspected, probably not statistically significant. Nonetheless, at the other 20 sites, there was a marked improvement in the safety history. However, the amount of the improvement at each site was distinctly different from that expected on the basis of the Design Manual's table.

Ron convened another meeting of the staff to review the results. He suggested they might want to re-visit the measures of effectiveness they used for prioritization, based on the research. The staff agreed the findings were interesting, but noted that the effectiveness measures were "in the manual" and should probably continue to be used. It was decided to contact Central Office to inform them of the research and suggest changes to the Manual.

Ron left the meeting to attend another meeting called by the District Engineer. Ron was being asked to explain why his section was over budget for the first 6 months of the fiscal year.

Benefits of improved system of safety information. A complete, integrated system of crash, traffic, and geometric data would enable better execution of safety-related programs. In the case here, the DOT is limited in the ability to relate crashes to the highway—in large part, because the geometric data files are not structured to support this effort. With an integrated system that includes all relevant geometric data, it would be possible to (1) improve estimates of high accident locations by more segmentation of the data and (2) investigate geometric and safety relationships. With the ability to retain history files of both crashes and geometry, post-construction evaluations could be performed of individual projects, and of programs as a whole. This would allow continual refinement of both safety effectiveness estimates and of prioritization procedures. The net result would be a more cost-effective use of the high accident treatment expenditures.

Summary. This scenario illustrates the importance of *maintaining key geometric data* related to highway safety. Of not-

able interest is roadside data. *Accessibility of data,* including both geometric and crash information, saves time in processing and analysis. The ability to maintain and build on *history of project effectiveness* can be as valuable to a State DOT as is maintenance of construction bidding records.

4. Reconstruction of a Major Urban Freeway Corridor

The Department of Transportation of a Midwestern state has identified the need to invest in reconstruction of an aging, deteriorating freeway serving the downtown of the state's largest city. The corridor includes many service interchanges and two major, multilevel system interchanges.

The freeway was originally designed and built in the early 1960s. It includes many features that the DOT staff now recognizes reflect outdated design. These include lack of full shoulders, many left-hand ramps, lane drops, short entrance tapers, and poor ramp geometry. The existing corridor operates at poor levels of service during much of the day. In recent years, the accident experience has worsened as traffic has increased. The DOT staff "know" that the combination of outdated design features and high traffic volumes are contributing to the facility's poor safety record.

Carolyn Nelson is appointed project manager in charge of developing a master plan for reconstruction of the corridor and its interchanges. A team of DOT staff and consultants is selected to begin the necessary engineering studies.

As work proceeds, it appears that there will be significant organizational and political inputs to corridor solution. The staff analyses indicate that mere reconstruction of the existing alignment in place could cost as much as $600 million. If a "modernized" design is produced that improves operations and eliminates the "known" safety problems, the price tag approaches $1 billion.

As work proceeds on design and environmental planning, public concerns about the alternatives begin to surface. Right-of-way, changes in access, noise, and other impacts are evident for the modernization plan. At public meetings and discussions with local officials, it is made clear to the DOT staff that their plans are being questioned. In particular, the public is demanding to know what the benefits will be if the modernization plan is approved. The staff is told that the governor and secretary of transportation want to do the right thing, but that the incremental investment of $400 million for "improvements" will have to be justified and explained to the public to garner their support.

Carolyn realizes they will need to make an effort to quantify expected benefits. The staff begin working on operational simulation studies to determine travel-time savings. One staff member, Maggie Wilson, is assigned the task of looking at expected safety benefits of modernization.

Maggie reviews the accident information obtained from the corridor for the last 3 years. She obtains data from Central Office that describe the statewide average accident rate for urban interstates. (Of course, the corridor being studied represents a significant portion of the data constituting the statewide average, making a comparison of limited value.) She talks to the Safety staff in Central Office to see if they have more refined information on accident rates at ramps, sections of highway, and so forth. She is told such information does not exist. She recalls that a reconstruction project was performed a few years ago in another city on the other side of the state. She calls the local DOT office to see if they have any information on the "before-and-after" accident experience, but is told that no studies were done.

Maggie next decides to do some research. She discovers research that is more than 25 years old that addresses issues of safety on freeway interchanges. The work is based on data from other states. It appears to Maggie that this research is the best information available.

She first decides to do a section by section, ramp by ramp analysis of the study area, attempting to derive effectiveness estimates for each link of the freeway. This, she estimates, will take her 6 weeks to complete. Carolyn Nelson is dismayed. The DOT does not have the time or budget to conduct such an exhaustive effort. Moreover, the Central Office staff warn Maggie not to read too much into the locations of the freeway crashes. Their experience, they tell Maggie, is that the crash reports aren't always accurate, and, in any event, coding errors for mileposts are common.

Maggie instead decides to conduct a systemwide analysis, using effectiveness measures from the research. She estimates that implementation of the modernization plan could produce up to a 20 percent savings in annual accidents. Her findings are included in the Draft Environmental Impact Statement.

Meanwhile, the operational studies are completed. DOT staff estimate that the average travel-time savings for a typical commuter will be 3 minutes with the modernization plan. These findings are also included in the Draft EIS.

Opposition to the project has continued to grow. The public are unimpressed with the 3-minute travel-time benefit. They do not see the need to spend the additional funds and incur other impacts based on it. With respect to safety, the public is more responsive. However, certain opponents of the project begin to scrutinize Maggie's work. They question its validity because of the use of outdated research and lack of specific focus on individual crashes.

All parties involved in the study recognize that improving safety will be the overriding consideration in a decision to modernize the corridor versus reconstruction in place. The perceived strength of the DOT's safety analysis will make the difference in what investment choice is made.

Benefits of improved safety information system. A better system of safety information would enhance the quality of analyses of design alternatives. It would provide the information at a higher confidence level and in a manner that would be accessible for large and complex studies.

A secondary (to the DOT) benefit of improved safety information would be the presence of data in sufficient quantity and quality to support research on the geometric relationships between safety and geometry. Such research would form the basis of DOT analyses that, in turn, are central to decisions regarding major public expenditures.

Summary. The above scenario illustrates an extreme but real implication of the ability of a DOT to definitively evaluate and communicate an expected safety benefit to the public. *Lack of confidence in location data* limit the ability to perform in-depth analyses. *Insufficient performance measures,* either from state or published research, make the task of estimating future safety benefits difficult. *The lack of history data* for similar previous projects relates to the problem of performance measures.

An improved system of safety information would provide the quantity, quality, and accessibility of data for Maggie to use. Her confidence in the data would improve the chances that analyses would be accepted by the public and decision-makers. Indeed, the availability of improved data, including historical data for projects, would provide a basis for research that could improve safety analyses by Maggie as well as others.

APPENDIX J

SYSTEM DEVELOPMENT CONCEPTS

TABLE J-1 System development concepts

Current Conditions	1997-2005	2005-2010	Beyond 2010
		Data Collection	
• Primarily manual field data-collection • Declining coverage of crashes, especially non-injury • Limited systems integration to avoid duplication of collection • Lack of key roadway data elements • No vehicle dynamics data • Many agencies experimenting with the use of portable computers for data collection • Inadequate and imprecise location of crashes and roadway elements	• Partial use of portable computing-devices • Partial use of automated methods (i.e., some use of automated measurement-devices such as laser measurement, and stereo ground-based or aerial imaging) to improve quality and capture desired elements previously lacking • Use of GPS & other location technologies for greater accuracy and precision for locating crashes and roadway elements • initial use of on-board measurement of vehicle dynamics • data-warehousing of traffic counts from detectors, and other count systems • Implement protocols to capture data from non-field sources (e.g., citizen complaints)	• data entry direct to computing device (virtually paper less) • integration of automated measuring devices • extensive use of imaging systems (ground-based and aerial, with initial use of satellite) to capture physical data • partial use of on-board measurement of vehicle dynamics • employ integrated systems to eliminate redundant data-collection	• real-time capture of crash data • extensive use of satellite imaging of physical and traffic data • use of satellite imaging to capture crash data • comprehensive use of on-board measurement of vehicle dynamics • voice/natural language interaction

TABLE J-1 System development concepts (*Continued*)

Current Conditions	1997-2005	2005-2010	Beyond 2010
Data Management			
• Safety-data residing in physically independent databases • File linkages exist for only a few basic databases • Minimal systems integration, requiring access primarily via file exchange and re-formatting, as necessary • Data handling a highly-manual process • General lack of quality assurance methods • Many non-traditional sources of safety data exist in manual systems	• Enhanced edits, primarily at point-of-entry • Data-quality specifications established • Comprehensive data quality-assurance programs • Develop data communications infrastructure • link safety-data systems, including non-traditional sources (e.g., maintenance, pavement management, citations and citizen complaints) to allow data-sharing • Implementation of data-warehousing concepts, including adequate history • integration of CADD files of as-built plans into roadway-database systems	• error trapping and editing at point-of-collection • extensive integration of systems and databases with enterprise-strategic data, allowing ready access across agencies and platforms, and avoiding duplication of data management • automation of data-quality review	• Use distributed databases to facilitate local error trapping and correction, as well as avoid overload of centralized systems • Full implementation of Data Mart concept
User Interface			
• Separate interfaces for safety data and design • GUI and limited use of GIS for safety data • CADD used for many design projects	• Rely principally on use of Standard GUI for user to conduct safety analyses, but begin to integrate CADD/GIS-based access	• Principally through CADD/GIS	• voice/natural language interaction • interaction through virtual reality

TABLE J-1 System development concepts (*Continued*)

Current Conditions	1997-2005	2005-2010	Beyond 2010
		Design Analysis	
• Limited use of inferential statistics • Inadequate use of experimental design techniques for evaluations	• Standardize on valid statistical techniques for HHL ID, pattern analysis, identification of over-representation, development of standards, and modeling • Standardize on valid experimental and quasi-experimental techniques to employ for evaluation, development of standards, and modeling • Direct provision of analysis support personnel for designers • Incorporate safety audits for proposed designs	• Use of agency-based crash-reduction factors and other prediction-devices (historical data) for impact-prediction • Adopt available IHSDM capabilities/models • Reflect refined design standards to enhance safety sensitivity in the policy review component and elsewhere	• Refine/enhance IHSDM capabilities and employ other advanced-modeling • Use simulation • Develop refined design standards to enhance safety sensitivity
		Results Presentation	
• User is primarily provided hard-copy tabulations • Information is usually not available in automated form, requiring user to do additional manual and computer-based analysis to generate basic business-graphics • Some use of statistical database programs and GIS, but with minimal integration	• Supplement tabular presentation of information with standard business graphics • Improve format of tabular information for easier interpretation • Enhance design of collision diagrams for greater usefulness • Produce a time line of site changes • Allow the designer to readily access individual narratives and diagrams from crashes, in a format easily interpreted • Create hyperlinks to support "drill down" analyses • Produce 3-D views of designs	• Adapt advancements from the science of data visualization • Experimental use of animation for dynamics presentation of designs and for portraying individual crashes	• Use virtual reality to experience a design or existing location • Use of animation of designs and crashes, based in whole or in part on simulation

TABLE J-1 System development concepts (*Continued*)

Current Conditions	1997-2005	2005-2010	Beyond 2010
		Decision Support	
• Primary decision support is design guides and standards • Limited use of tables linking crash patterns, potential causes, and candidate countermeasures • Not usually support in aspects dealing with data manipulation, analysis and results presentation	• Adapt and integrate existing materials into the design process, relating crash attributes, contributing circumstances and candidate countermeasures • Establish decision-support technical assistance function within design agency to assist designers directly with data analysis and interpretation issues	• Use expert systems tools to provide support to the user at various stages of analysis and decision-making	• Use advancements in artificial intelligence to support the user at various stages of the decision-making process

APPENDIX K

PROPOSED INITIAL RESEARCH AND DEVELOPMENT PROJECTS

A process was followed to develop an initial program of research and development for the DDSS which involved significant interaction with the Project Panel. This took the form of discussions, evaluation sheets, and comments on draft statements. The result is the final set of project statements in this appendix. Figure 14 in Chapter 4 of this report summarizes the projects. The following pages contain the statements. The format was provided by NCHRP, to fit with their review and evaluation process for selection and funding.

Research Statement 1

I. PROBLEM TITLE

New and Improved Methods for Displaying Safety Information to Support Design Decisions

II. RESEARCH PROBLEM STATEMENT

When a designer is considering the conditions of an existing site, he or she should be enabled to readily interpret the crash history and other problems in terms of potential contributing circumstances, as well as what changes have occurred in geometry and traffic control in the past. This will help to identify possible strategies for addressing safety and operational problems that have been identified. If an operational history can be provided for the site in an effective way, it will help avoid previous pitfalls and arrive at informed decisions.

Collision diagrams offer one of the few means by which designers today display crash history graphically. Means are needed to enhance the basic collision diagram to make interpretation easier for the analyst. In many cases, there is visual clutter. In addition, some information appears on the diagram as text, which can be difficult to synthesize, especially when there are a number of crashes to deal with at a location. Even within the basic concept of the collision diagram, improvements could be implemented to assist the designer in interpreting the information.

In addition to the collision diagram tool, more effective graphic portrayals of information can be very helpful, especially when they replace tabular displays. However, basic business graphics are not often employed to help designers interpret safety data, unless the individual creates the charts and graphs. A more effective means is needed to supply the designer with graphic information.

The geometric and traffic control history of a site is often not available to a designer, even though this type of information might help avoid past pitfalls and provide insights into new approaches for improving a site. The use of graphic techniques for displaying the history of site attributes would facilitate safety considerations at a site.

Within the next few years, almost all design will be performed on CADD systems, some with integrated GIS capabilities. If project-level safety information of the type described above is to be regularly employed by designers, the most effective means for facilitating this is to develop for them the capability to do so within their regular working environment (i.e., CADD/GIS).

We are in the information age. As more information becomes available, there is a greater need to present it in a way in which it is immediately useful in a cost-effective manner, rather than overwhelming and confusing the user with numbers.

III. RESEARCH OBJECTIVES

This project is proposed to develop and demonstrate the usefulness of improved safety information displays in gaining better consideration of safety in decisions on design projects. The displays to be focused upon were identified under NCHRP Project 17-12 as the most promising ways to help designers interpret safety data.

Specifically, the project is to achieve the following:

1. Development and demonstration of a method for displaying the history of site attributes of interest in making safety-based design decisions.
2. Development and demonstration of an "intelligent" collision diagram, which provides the user with "assistance" in interpreting the information, through techniques such as improved graphic displays and object-oriented links to further details regarding information displayed on the diagram.
3. Demonstration of how standard business graphics may be effectively employed to improve the display and interpretation of safety data.
4. Development and demonstration of a means to produce these two types of information displays in a CADD/GIS environment of the type to be commonly used by designers.

IV. RESEARCH APPROACH

The research effort will design and produce a system to display safety data for designers in one or more CADD/GIS environment(s) typically in use. The project will have two major phases:

1. System design; and
2. System development and demonstration.

The tasks for system design will include the following:

1. Gathering and reviewing relevant literature and software, including information about related practices of safety and design agencies in the United States and abroad.
2. Assessing the information for use in the project, and to help further detail project directions.
3. Creating mockups of a proposed set of displays of safety data, including site history, improved collision diagraming, and use of business graphics. The mockups will allow definition of the data needed to generate the desired displays and assess current availability of those data.
4. Identifying the appropriate real-world sources for data and systems, for use in developing and demonstrating the proposed displays.
5. Developing system specifications, including the analytical processes required.

Tasks for developing the information system will include the following:

1. Assessing, selecting, and integrating available software and creating new programs, as needed.
2. Generating displays for test scenarios.
3. Performing an assessment of the system. The resulting system will be presented to selected designers who will be asked to assess the usefulness of the new system and recommend modifications thereto.
4. Making modifications to the system, in accordance with the user assessments.
5. Developing a final system and a report containing recommendations for transfer of the new technology to the design community, and a compendium of graphic methods for representing safety information in a manner to facilitate interpretation.

V. ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

$250,000 over a period of 30 months

VI. URGENCY, PAYOFF POTENTIAL, AND PRODUCTS

The project is urgent. It represents an important part of a long-range program of research and development intended to improve the quality and cost-effectiveness of safety-related design decisions. It complements the efforts by the FHWA on its development of an Interactive Highway Design Model, an ongoing research program that will begin producing software in the next 3 years. It also will enhance the value of the efforts of many state departments of transportation to develop improved safety management systems. The project has high payoff potential, because it will be building upon proven technologies and practices and making it easier for users to access and use safety information.

There will be several related benefits to this work, which will have impacts beyond the design community. The results of this work will highlight the particular data needs that highway designers have. This will allow unique needs to be identified and adequately considered by those who collect and manage the data. It will also make that same group aware of the overall information needs that the design community has and the potential role for collectors and managers of data to supply those needs. Finally, the results will provide a further justification for funding of improved technology for all aspects of delivery of information, starting with data collection and proceeding through to the presentation of finished information to the end user. Finally, the project will highlight the usefulness of this information for purposes other than project design decisions for safety.

Research Problem Statement 2

I. PROBLEM TITLE

Assessment of Tools and Techniques for Improving Accuracy when Documenting the Location of Reported Crashes

II. RESEARCH PROBLEM STATEMENT

One of the major problems faced by those desiring to do site-specific safety analyses, such as highway designers, is that the quality of reporting of the location of individual crashes is very low. In a significant number of crash reports, either location data are not provided at all, they are imprecise, or they are inaccurate. Furthermore, the nature of the problem will vary among law-enforcement agencies, as well as individual reporting officers, resulting in an inherent inconsistency of the data set. Initial field trials are being made by FHWA of the use of some new technologies to improve documentation of crash location, as well as the quality of other aspects of crash investigation. In addition, many cities and states have independent demonstration, or early-implementation programs, to use new technologies to improve crash reporting, including the determination of crash location. The FHWA work is being documented; early results of the FHWA field trials indicate that some technological and non-technological factors must be overcome. The results of some of the other efforts are being made available to the profession through a federally funded activity being performed by the International Association of Chiefs of Police (IACP). However, there is a need to synthe-

size this wide range of experience and to evaluate the technologies and related non-technological factors, in the light of this early experience. Recommendations are needed for a total systems approach for improving accuracy, precision, and coverage when reporting crash location.

III. RESEARCH OBJECTIVES

The basic objective of this project is to arrive at recommendations for one or more systems that reporting agencies may use to accurately and precisely report the location of virtually all crashes being entered into a safety database. As a secondary objective, the project seeks to provide a compendium of methods in use or being tested for improving the reporting of crashes, including crash location.

IV. RESEARCH APPROACH

The research is designed to first identify the applicable technologies, then select the appropriate ones to evaluate. The following tasks are envisioned:

1. Develop a compendium of technological and other strategies in use, or potentially useful, for improving the reporting of crash location. This will be achieved by a combination of literature search and contact with operating agencies. Contacts with FHWA and use of the IACP database, along with further contacts with selected operating agencies, will provide the range of experience desired.
2. Document and synthesize information on recent and current activities for improving location reporting (and other aspects of crash reporting).
3. Developed a process to evaluate alternative systems for improving location reporting.
4. Develop descriptions for a set of alternative candidate systems for improving location.
5. Evaluate the candidate systems and arrive at recommendations for implementing cost-effective systems.
6. Develop a final report to document the work, including a compendium of methods in use, or being tested, for improving the reporting of crashes, with emphasis upon crash location. Recommended systems will be presented, and implementation guidelines will be provided in the report.

IV. ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

$50,000 over a period of 12 months

VI. URGENCY, PAYOFF POTENTIAL, AND PRODUCTS

This research is urgent. It represents the single most significant constraint to effective use of crash data in the highway design arena today. Many agencies are experimenting with technological solutions, but some early results from FHWA demonstration projects indicate that there is significant interplay between the organizational context, including type and training of personnel, and the effectiveness of the new systems for establishing location. There is an urgent need to organize the experience of many different, and often unrelated, demonstrations and prototype activities. Generalized findings may then be developed which can help those in state and local transportation and law enforcement agencies who collect the data that the design community desires to use.

Research Statement Number 3

1. PROBLEM TITLE

Assessment of the Potential Role for Safety Audits in a Design Decision Support System

II. RESEARCH PROBLEM STATEMENT

The highway design process is undergoing significant change, as advances in technology and knowledge occur. NCHRP Project 17-12 outlined a proposed Design Decision Support System (DDSS) intended to provide engineers at each stage of the design process with the tools and techniques to incorporate safety in their decisionmaking. The Federal Highway Administration is developing a major, multiyear research effort entitled Interactive Highway Safety Design Model (IHSDM). The vision of FHWA is that designers would have the data, tools, and knowledge to interactively assess safety and operations as they study alternative designs. With the implementation of the IHSDM, a number of tools will be made available to designers to produce independent assessments of various aspects of a given design.

An important aspect of the proposed DDSS will be the assistance afforded the designer in summarizing and interpreting the results of the multiple analyses. This requires a conceptual framework to structure the approach. One potential framework is the *safety audit,* a technique that has evolved in Europe and Australia, but is relatively new to North America.

There is a need to investigate the utility of the safety audit technique as a model for the DDSS. Research is needed to assess the safety audit technique as it is currently used by others and test it against the objectives of the IHSDM and DDSS as outlined by NCHRP Project 17-12.

III. RESEARCH OBJECTIVES

The primary objective of the proposed research is to identify the potential role for safety audits in a design decision support system for safety. This would include an assessment of the safety audit concept applied to the evaluation and synthesis of the results of analytical models and techniques envisioned for FHWA's IHSDM.

The research may result in the safety audit concept having limited utility to the DDSS concept. This would not necessarily imply that safety audits have no role in North American design practice. There is clearly a secondary objective, which would be to provide background, enhance understanding, and identify other roles or uses for the safety audit technique.

IV. RESEARCH APPROACH

The research would focus on establishing an understanding of the safety audit approach as it has evolved elsewhere. Organizational, technical, and other differences in design practice among international and North American agencies and the relationship of these differences to the applicability of safety audits would be investigated. The research approach would address the full range of project types, including new construction, major reconstruction, 3R, and maintenance activities. The research would also focus on the full range of highway types, including rural and urban roads and streets and two-lane, multi-lane, and full access controlled facilities.

The following task outline is envisioned:

1. Review and synthesize the literature and practices relating the concept of safety audits. This task will focus on current practices outside North America.
2. Investigate the design process in those countries where safety audits are prevalent. Identify organizational differences and similarities in the design process that may address the utility or applicability of safety audits to North American practice. Examples include the role and use of design standards and criteria in design, prevalent concerns over tort liability and their impact on design, the role of the public and other agencies in design decisionmaking, and trends in alternative project delivery.
3. Review the DDSS proposed in NCHRP Project 17-12. Evaluate the potential technical role for safety audits or an adaptation of them to the DDSS. Include the full range of design decisionmaking, from planning to final design. Demonstrate the applicability of safety audits through examples of actual cases.
4. Evaluate and recommend the role or roles for safety audits within the context of North American design practices. Address organizational or other changes needed to optimize the utility of safety audits. Demonstrate the potential benefits of the safety audit process for the full range of highway types and design problems.
5. Develop a final report documenting the project and the recommended uses of safety audits. Include recommendations for their implementation.

V. ESTIMATE OF PROJECT FUNDING AND RESEARCH PERIOD

$75,000 over a period of 12 months

VI. URGENCY, PAYOFF POTENTIAL, AND PRODUCTS

The project is urgent. Safety audits have just recently become visible. FHWA's IHSDM is proceeding toward implementation. The timing is appropriate for tying together advances in technical and design process to a unified approach.

The payoff potential for this relatively modest effort is significant. The process of incorporating safety audits may greatly enhance an agency's ability to document the safety impacts of design decisions, thereby improving its ability to withstand tort lawsuits. The quality of design decisions can be improved through institution of a new process that is intended to explicitly consider safety. Such a process is not commonly applied in North American practice.

Research Statement Number 4

I. PROBLEM TITLE

Assessment of the Usefulness of the Current State of the Art of Decision Support Systems for the Design Decision Support System for Safety

II. RESEARCH PROBLEM STATEMENT

A concept for a Design Decision Support System for Safety has been recommended and detailed under NCHRP Project 17-12, *Improved Safety Information to Support Highway Design.* A key feature of the proposed Design Decision Support System for Safety is the decision support module. This module requires extensive application of the technologies of artificial intelligence, including expert systems. This science is evolving, but will probably not be fully ready for application for several years. In the interim, however, much progress has been made in this area and a related one termed "executive" information systems. These computer-based methods are being used extensively by commercial enterprises in highly competitive fields. The new technologies may be applicable for developing an initial implementation of a Design Decision Support System for Safety.

The development of a Design Decision Support System for Safety should not attempt to "reinvent the wheel." Instead, advantage should be taken of the technologies being developed in commercial and other arenas, to the extent possible. An important early task in the development of the Design Decision Support System for Safety, therefore, will be an assessment of the state of science in DSS's. This should lead to an approach to development which takes maximum advantage of available systems, as well as accounts for their further evolution. This will help establish the foundation for the overall development process for a Design Decision Support System for Safety.

III. RESEARCH OBJECTIVES

The primary objective of the research is to identify one or more commercially available decision support systems that may be recommended for use to create an initial implementation of the decision support module in the Design Decision Support System for Safety. A secondary objective is to arrive at a detailed definition of the specifications for a decision support module for the Design Decision Support System for Safety, which can be used for guidance during its further development.

IV. RESEARCH APPROACH

The following tasks are envisioned:

1. Identify and document available decision support packages.
2. Develop a procedure to assess the alternative packages and arrive at conclusions regarding their current applicability to the DDSS.
3. Perform an initial assessment to narrow the alternatives. The assessment will involve the installation and operation of the systems, using a set of test decision scenarios for which appropriate data can be readily provided. Where feasible, application of the packages in a Design Decision Support System for Safety context will be demonstrated. This will be followed by making contact with selected current users of those systems remaining for consideration after the initial assessment. Some example uses of the packages, and the user's experience therewith, will be documented.
4. Develop a set of system requirements for the decision support module of the proposed Design Decision Support System for Safety.
5. Prepare a report documenting the project, including recommendations for additional adaptations for decision support systems in general, and specifically for the packages assessed.

V. ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

$150,000 for a period of 24 months

VI. URGENCY, PAYOFF POTENTIAL, AND PRODUCTS

This project is urgent. It represents an important part of a long-range program of research and development intended to improve the quality and cost-effectiveness of safety-related design decisions. The work will produce recommendations for the adaptation and adoption of one or more of the available packages for an initial implementation, as well as specifications for the decision support module, of the Design Decision Support System for Safety. It ties directly into parallel efforts by the FHWA on their Interactive Highway Design Model, an ongoing research program that will begin producing software within the next 3 years.

As state and local highway design agencies experience loss of highly experienced personnel, less experienced people are replacing them. Furthermore, there are efforts underway to upgrade the quality and increase the content of safety data available for analysis. The individuals remaining in design agencies to deal with these data will make only limited use of it unless it is transformed into useful information and assistance is provided for its application. Decision support systems offer the potential for helping provide the information and assistance needed. If a Design Decision Support System for Safety is to have a high payoff potential, this proposed project is necessary to establish the appropriate foundation for its development.

Research Statement Number 5

I. PROBLEM TITLE

Development and Demonstration of Improved Methods for Safety Data Collection

II. RESEARCH PROBLEM STATEMENT

Previous research has outlined the need to improve the quality and quantity of data used to characterize safety on the highway system. This need is countered by continuing pressures on governmental agencies to reduce or eliminate many functions, including the development and maintenance of databases.

There is a need to demonstrate to the highway and law enforcement community that means exist to improve both the quality and cost-effectiveness of collecting those data necessary to safety on the highways. Such means include a wide range of technological advances and unique applications.

This research would outline technological tools and their application to data collection, quality control, and database management. It would address relative costs of hardware, software, and training and draw comparisons between existing procedures and new or proposed methods. The research would highlight the benefits of the new methods through actual field demonstrations. The research is envisioned as including, but not necessarily being limited to, an evaluation of the following methods and technologies:

1. Use of portable computers for collecting and recording physical highway data in the field,
2. Development of crash report from software to provide direct "guidance" for field interviews,
3. Application of digital cameras to acquire and store images and other similar data,
4. Use of portable laser measurement devices to improve the quality and speed of obtaining measurements at sites,

5. Use of instrumented vehicles to obtain frequently missing or difficult-to-collect data such as roadside obstacles and slopes,
6. Use of low-level flight digital aerial inventory technologies for roadway inventories, and
7. Use of satellites for collection of traffic volume and speed data.

III. RESEARCH OBJECTIVES

The primary objective is to introduce the concepts and determine the feasibility of applying specific new techniques to the acquisition of crash, roadway inventory, and traffic data. Corollary objectives include the following:

1. Assessment of the relative "costs" and difficulty of using the technologies, including personnel and training requirements, hardware requirements, and software investments.
2. Assessment of the effects of each method's use on the quality of the data used for safety analyses.

IV. RESEARCH APPROACH

The research would continue from NCHRP 17-12, updating the list of technologies applicable to crash, roadway, and traffic volume data collection. Information would be obtained describing use, either experimental or adopted by any agency. On the basis of the available funds and priorities of the panel and researchers, the most promising technologies requiring further assessment would be selected for further development and field demonstrations. The following tasks are envisioned:

1. Review the state of the science of technologies applicable to crash reporting, geometric and field data inventories, and traffic speed and volume measurements.
2. Prioritize technologies, and design demonstration experiments for select ones.
3. Select sites, and design and program data collection and recording protocols for those selected.
4. Establish an evaluation approach.
5. Acquire necessary hardware, and develop software.
6. Conduct field tests, including appropriate pre-testing and revisions, to test procedures and protocols.
7. Analyze results, including assessment of improvements to data quality, reductions in data acquisition time, and/or cost.
8. Document results through final report, CD-ROM, video, or other appropriate medium.

V. ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

$300,000 over a period of 30 months

VI. URGENCY, PAYOFF POTENTIAL, AND PRODUCTS

The project is urgent. There is a growing trend in law enforcement to eliminate the collection of property-damage-only crash data, primarily because of budget and time constraints. Also, there has already been much work in the law enforcement field in review and experimentation with the use of portable computing devices. Such experimentation, however, has been somewhat limited. It is important for law enforcement agencies to incorporate highway safety data needs as they address their use of technology and procedures for collecting crash data.

In a similar vein, highway agencies are undergoing change in their ways of doing business. Many are experimenting with the use of various data inventory systems. However, the focus on many of these is not sufficiently broad to include data collection needs associated with geometric features related to safety. There is a need for agencies to understand and include such considerations before they commit to procedures, hardware, and training in the use of new technologies.

The payoff to the highway community could be tremendous. More data and better data quality are necessary to improve safety-related decisionmaking. Appropriate use of advancing technologies is the only means of achieving such data, particularly in an era of reduced government. Better safety data will eventually mean greater understanding of safety impacts, more cost-effective safety-related decisions, and, hence, better use of highway safety investments.

Research Statement Number 6

I. PROBLEM TITLE

Demonstration of the Means to Collect, Manage, and Use New Sources of Highway Safety Data

II. RESEARCH PROBLEM STATEMENT

NCHRP Project 17-12 and other recent research have documented shortcomings in the availability and quality of data describing highway crashes. Such shortcomings limit the ability of designers to understand safety effects and act appropriately. The same research highlighted opportunities to capture and apply data being obtained by others and incorporate these data into safety databases. This research would demonstrate the means of obtaining, managing, and using alternative sources of crash and roadway data.

There are data sources outside the context of a normal crash investigation which are rarely, if ever, used by safety analysts or designers. Such data are often not readily accessible or in a form that can be applied to the necessary analysis. Three examples, outlined below, illustrate such sources and their potential utility.

Supplemental crash investigation data for serious injury and fatal crashes are often collected by different investigators than those producing the original crash report. The sup-

plemental investigator is often highly trained, in contrast to the general patrol officer who may possess little training or technical skills in the area of crash investigation. Data gathered by supplemental investigators may result in altered findings regarding causation or contributing factors. Such data may be of higher quality and more detailed, particularly with respect to key roadway and environmental factors such as the roadside and pavement friction.

Supplemental crash data, although of considerable potential value, are generally unused by safety analysts and designers. There is a need to determine the feasibility of acquisition, storage, and use of this potentially valuable data source.

Site images, placed within a readily accessible roadway database in digital format, are another source of data potentially useful to safety analysts or designers. Under current practices, analysts are often without a current, reliable record of the physical and traffic control features of a site at the time a crash occurred. Improvements in roadway inventory practices can overcome this problem. However, in addition to advances in dimensional data, visual images of sites would be helpful to analysts in interpreting the data and crash.

There is a need to investigate the technology and current use of videologging practices and conversion to digital images to the problems of crash site characterization. Issues of data storage technology must be addressed.

Traffic Operational Data for a specific location and period are virtually never available without cost-prohibitive special studies. Traffic volume data, including hourly demand volumes, turning movements, and vehicle classification are all useful in understanding the circumstances of a given crash. Yet, such data are generally unavailable, except at a nearby location that may be some distance from the crash site. Measures of vehicle speed and speed distribution at a location can be critical to understanding the relationship between a site design characteristics and safety. Again such data are generally not available, requiring costly special studies or inference using the best available, nearby automatic count locations.

Advances in the use of alternative sources of volume and speed data offer opportunities for analysts and designers to broaden their availability of data. Such advances include the use of computerized traffic signal systems that measure and store traffic volumes on a continuous basis; satellites and advanced aerial photo technology that make feasible real-time traffic volume and speed studies, and other technological advances.

III. RESEARCH OBJECTIVES

The objective of this research is to evaluate and demonstrate the application of three types of existing safety data to the problem of crash characterization. Focus is placed on types of data not currently employed by most safety analysts in design or design-related work.

IV. RESEARCH APPROACH

The research would focus on, at most, three specific data types—supplemental crash data, video imaging, and traffic volume and speed data. The following tasks are envisioned:

1. Document current practices for the supplemental investigation of crashes, including data collection, management, and use. Document current practices in the acquisition and use of videolog or digital imaging of the roadway environment. Document current practices and research in the area of collection and use of traffic volume and speed data from advanced computer traffic signal systems, satellites, or other devices.
2. Identify experiments to demonstrate the use/applicability of the above data. Select sites or locales to conduct field tests.
3. Develop concepts for the application of these new data sources in the highway design process. Identify necessary revisions to data management practices to make such data accessible to the appropriate users.
4. Conduct field tests.
5. Evaluate and assess the results, and make recommendations regarding the feasibility of the data sources and their acquisition to the design process.
6. Prepare a final report, including guidelines on the selection and use of the technology and the systems improvements needed to integrate these into the information system.

V. ESTIMATE OF PROJECT FUNDING AND RESEARCH PERIOD

$200,000 over a period of 24 months

VI. URGENCY, PAYOFF POTENTIAL, AND PRODUCTS

The project is considered urgent. The design community needs improved quality of safety data. Alternative sources of data available that, while not traditionally considered available for such use, can provide significant improvement in the ability to analyze the safety history of project sites. As highway and law enforcement agencies improve their information systems, it will become easier than ever to apply new technologies to capture these data so that they may be readily accessed. This effort will help demonstrate to agencies the potential for significant improvement in their analytical systems.

The payoff to the highway community will be improved quality of data. It will allow agencies to make additional use of data already being collected for other purposes, thereby making its collection more cost-effective. Better safety data will eventually mean greater understanding of safety impacts, more cost-effective safety-related decisions, and hence, better use of highway safety investments.

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The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purpose of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. William A. Wulf are chairman and vice chairman, respectively, of the National Research Council.

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation

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