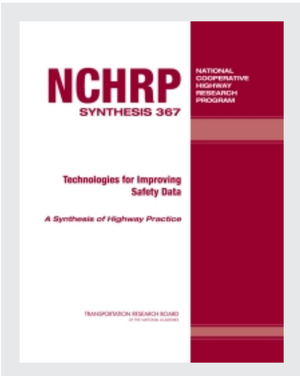

Technologies for Improving Safety Data

DETAILS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 367

Technologies for Improving Safety Data

A Synthesis of Highway Practice

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SUBJECT AREAS
Planning and Administration, and Safety and Human Performance

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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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

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

This synthesis will be of interest to state transportation agency personnel, as well as to others who work with them in the area of safety. It provides information for state departments of transportation (DOTs) on new technologies for the acquisition, processing, and overall management of crash, roadway inventory, and traffic operations data. The objective was to summarize the current state-of-the-practice and state-of-the-art use of technologies for efficient and effective collection and maintenance of data for highway safety analysis. Information is presented about the U.S.DOT developing new safety and analysis tools to help state DOTs identify safety problems and countermeasures to increase highway safety. States are limited in their abilities to make informed decisions about the allocation of scarce safety resources because many states lack the database elements and linkages between databases to compile the data sets required by the new safety analysis tools.

This synthesis effort contains information received from three individual surveys, developed to gather state-level information about the core safety data areas—crash, traffic operations, and roadway inventory. These surveys yielded approximately 60 returns from 34 different state DOTs and, along with a literature review, Internet search, and follow-up telephone contacts and interviews, generated the information used in this synthesis.

Jennifer Harper Ogle, Clemson University, Clemson, South Carolina, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

TECHNOLOGIES FOR IMPROVING SAFETY DATA

SUMMARY

With an increased focus on safety, the U.S.DOT, specifically FHWA, has developed new safety analysis tools to help state departments of transportation identify safety problems and potential countermeasures to increase the safety of their highways. Consequently, the development of the safety analysis tools has introduced a new set of requirements for safety data, such as detailed road design data and comprehensive traffic volume data. Safety data are no longer merely crash data, but rather a system of interconnected databases featuring roadway characteristics, roadside features, traffic operations, and driver and vehicle history in addition to crash data. Unfortunately, many states currently lack the database elements and linkages between databases to compile the data sets required by the new analysis tools, which can limit the states' ability to make informed decisions regarding allocation of scarce safety funds.

In part, the inadequacies of state safety data systems often result from the distributed nature of the data collection and maintenance functions. There are three primary data sources required for most of the aforementioned safety analysis tools; data related to the crash, roadway, and traffic. In each state, there may be multiple levels within an agency or even multiple agencies involved in collecting, maintaining, and analyzing the primary data sources. Limited agency budgets also play an important role in decisions regarding data collection, storage, and processing. State Traffic Records Assessments, promoted by NHTSA and FHWA, indicate that crash reporting thresholds are increasing, although the total number of crash data elements being collected is decreasing. These changes are often the result of the budget constraints facing most public agencies.

In August 2005, the authorization of the highway bill SAFETEA-LU once again placed highway safety at the forefront of government's focus on transportation. Section 148 created a new core safety infrastructure grant program providing for safety conscious planning and data system improvements. Under the new bill, each state must develop a Strategic Highway Safety Plan and implement a Highway Safety Improvement Program that will identify safety problems and opportunities, be *data driven*, and coordinate with other highway safety programs in the state. SAFETEA-LU requires states to have in place a crash data system with the ability to perform safety problem identification and countermeasure analysis on all public roads.

Given the new set of safety data requirements, the current state of safety program coordination and safety data systems, and the Highway Safety Improvement Program requirements mandated in the SAFETEA-LU reauthorization, highway safety programs are once again at a crossroad. There is an urgent need to improve the efficiency of the data collection, processing, and evaluation required for successful safety programs at the state and municipal levels. SAFETEA-LU funding levels should provide a good foundation for the changes that need to occur, although many states will require much higher levels of funding to make the necessary improvements in data systems. To bridge the gap from system inadequacies to effective safety data, states will have to turn to more efficient and effective technologies to attain a sustainable data collection and maintenance system. This synthesis provides information on new technologies for the acquisition, processing, and overall management of crash, roadway inventory, and traffic operations data.

The objective of this synthesis was to summarize the current state-of-the-practice and state-of-the-art utilization of technologies for efficient and effective collection and maintenance of data for highway safety analysis. Technologies have been suggested by previous research reports as providing a means by which to overcome many of the limitations surrounding safety data. This synthesis documents a number of successful implementations of technologies whereby the following measures of safety data were improved:

- Timeliness,
- Accuracy,
- Completeness,
- Comprehensiveness,
- Efficiency, and
- Integration.

A multifaceted approach was used to define safety data requirements and identify technological solutions that enhance these safety data measures. Six specific tasks were undertaken:

1. Examination of new safety analysis tools to identify data requirements.
2. A survey of states to determine compliance with identified data requirements (crash, roadway inventory, and traffic operations) and to discern types of technologies used to collect, process, and manage the three types of data, as well as the extent of their use. Of the 150 surveys distributed, approximately 60 from 34 different states were returned.
3. A follow-up with states to ascertain additional information or clarify information on technology use.
4. Development of a matrix of available technologies to support collection, processing, and maintenance within the three primary data categories.
5. Completion of a literature search on technologies identified from the survey, general knowledge of the area, and through suggestions from the research review panel.
6. Development of a matrix matching technologies to specific data requirements to guide agencies seeking to employ new technologies to support safety information systems.

The survey of states indicated that federally mandated data programs such as those for bridges, railroad crossings, and highway performance have a strong effect on states' comprehensive collection of data. Fewer than half of the states responding indicated having collection systems for geometric elements for items such as horizontal and vertical curvature—design elements with known relations to safety. Although numerous data systems exist, few states reported using new technologies or undertaking efforts to research new methods for data collection and maintenance. Surprisingly, a number of the data elements are still being collected with pen and paper. Most states responded positively to having geographic information systems; however, the linear referencing systems and archival systems in widespread use have considerable limitations. A number of states indicated capture of electronic crash reports, but few had widespread use throughout the state.

The survey and literature search uncovered many technologies currently in existence that can provide numerous efficient means in safety data acquisition, processing, and management. Unfortunately, many of these technologies are not being fully or even partially integrated into the safety data process. The synthesis focused on the review of technologies that had been used successfully in one or more states. The technology reviews included an array of technologies from global positioning system receivers for crash data collection to enterprise data systems for serving multiple data sets to an entire organization or multiple organizations.

In general, some of the technologies had limited applications, whereas others encompassed all data types and data sources. To help agencies make use of the technology references, a matrix of technologies and data elements has been included in the appendixes. For agencies wishing to use one of the new safety analysis tools, there are also references to which data elements relate to each of the software tools. Although the matrix will help to identify potential technologies, a thorough evaluation of the advantages and disadvantages of each technology will be required. For example, the choices regarding linear referencing systems and use of dynamic versus static road characteristics databases have dramatic effects on a states' ability to use data systems for safety analysis. Some are much better than others, yet some choices have positive implications for one database and negative implications for others. These choices are difficult and must be consciously considered upfront in the design and implementation of a safety data system.

CHAPTER ONE

INTRODUCTION

In 2004, 42,636 people were killed and 2,788,000 were injured in an estimated 6,181,000 police-reported motor vehicle traffic crashes (*1*). AASHTO predicts that if current crash trends continue, "one out of every 90 children born today will die violently in a motor vehicle crash (*2*). And 70 of every 100 will be injured in a highway crash at some point in their life, many more than once." Behavioral programs to increase the use of safety belts and installation of roadside appurtenances are among many diverse treatments that have been implemented with the intent to reduce crash numbers and severity. Although implementation of treatments such as these has reduced crash rates considerably since the mid-1960s, the last several years have shown little in the way of significant reductions (*1*). These trends are troublesome and have led to a revitalized focus on safety in the United States.

BACKGROUND

With an increased focus on safety, the U.S.DOT, specifically FHWA, has developed new safety analysis tools to help state departments of transportation (DOTs) identify safety problems and potential countermeasures to increase the safety of their highways. The safety analysis tools include the Interactive Highway Safety Design Model (IHSDM), SafetyAnalyst, and the *Highway Safety Manual* (*HSM*). Consequently, the development of the new safety analysis tools has introduced a new set of requirements for safety data, such as detailed road design data and comprehensive volume data. Safety data are no longer simply crash data, but rather a system of interconnected databases featuring roadway characteristics, roadside features, traffic operations, and driver and vehicle history in addition to crash data. Unfortunately, many states currently lack the database elements and linkages between databases to compile the data sets required by the new analysis tools, thus limiting the states' ability to make informed decisions regarding allocation of scarce safety funds.

For instance, during the development of the IHSDM, researchers were limited to using data from only four states for the development of crash prediction models. The requirements for data quality and comprehensive linkages between safety-related databases left few states eligible for inclusion in the model development. In some cases, the data had to be compiled specifically for use in the modeling tasks. The information necessary for developing accident models for two-lane rural roads, in conjunction with IHSDM, was obtained from two states: Minnesota and Washington (*3*). Multiple sources, including Highway Safety Information System (HSIS) files, photographs and video-logs, and construction plans, were compiled to obtain the necessary data for this study (*3*). The HSIS files contain data on accident severity, traffic, lane width, shoulder width, and alignment (*3*). In Washington State, additional horizontal and vertical alignment, channelization, driveway density, and clear zone data were acquired from photographs and video-logs, and in Minnesota the same was collected from hard-copy construction plans (*3*). Validating this study posed further problems. Additional years of data had to be collected and compiled from California, Michigan, Minnesota, and Georgia (*4*). Aside from the lack of comprehensive databases, the analysis was impeded by the array of coding schemes used by the different states. For example, the criteria for a crash being "intersection-related" had to be established, because it was coded differently in each of the four states. The consistency of accident locations and the number of decimal places for global positioning system (GPS) coordinates were also issues in the Georgia data that had to be resolved before the study could be validated (*4*).

In 1999, Pfefer et al. (*5*) conducted a study to identify areas where improvements could be made to safety information systems to allow designers to better address safety issues on our highways. The study included a methodical review of safety information requirements, accident reporting requirements, traffic and roadway data collection systems, technology use, and institutional issues. A number of limitations regarding the crash, roadway, and traffic data were noted including:

- Lack of precision measurement and reporting (i.e., collection of daily traffic volume without specific information about peak-hour traffic volumes).
- Lack of automated tools (i.e., over pen-and-paper-based forms, technology allows for more efficient and effective collection and management of safety data).
- Inadequate coverage [i.e., traffic data collected for the Highway Performance Monitoring System (HPMS) does not include rural minor collectors or local roads].
- Incomplete data or missing data elements (i.e., incomplete data may arise owing to an oversight by the officer in the field, and missing data from noncompliance with minimum requirements). Lack of history (i.e., road inventory systems are typically built on dynamic

databases that are constantly updated with little or no information saved regarding the history of the individual elements).
- Integration issues (i.e., inaccurate or nonexistent data elements preclude linkages between databases maintained by different agencies).

The inadequacies of state safety data systems often result, in part, from the distributed nature of the data collection and maintenance functions. There are three primary data sources required for most of the aforementioned safety analysis tools. These are data related to the crash, roadway, and traffic. In each state, there may be multiple levels within an agency or even multiple agencies involved in collecting, maintaining, and analyzing the primary data sources. Pathways for data sharing and the development of common elements across data sets are critical to data linkage and the ultimate value of the data systems. Several recent reports (*2*, *5–11*) address the critical nature of interagency coordination and provide strategies for overcoming institutional obstacles.

Limited agency budgets also play an important role in decisions regarding data collection, storage, and processing. State Traffic Records Assessments, promoted by NHTSA and FHWA, indicate that crash reporting thresholds are increasing, although the total number of crash data elements being collected is decreasing (*5*); changes often a function of the budget constraints facing most public agencies. In realization of these problems, AASHTO developed a "Strategic Highway Safety Plan" (*2*), which includes management as one of the plan's six core elements. This element focuses on the problems associated with gathering and analyzing crash data. The two goals associated with this element are to (1) improve the information and decision support systems and (2) create more effective process and safety management systems. AASHTO views "Good . . . data" as the "backbone of an effective safety management system" (*2*).

Finally, the impacts of legislation on highway safety programs are real. Under the ISTEA, each state was required to develop a Safety Management System (SMS) (*12*). By 1994, all states had developed a work plan for an SMS (*9*). However, in 1995, the National Highway System Designation Act made the implementation of the SMS optional (*9*). With this option, approximately half of the states decided not to implement the SMS (*9*). In a follow-up survey conducted in 2000 (*13*), 80% of states without an SMS reported that the regulation's change from required to optional was the major reason for abandoning the efforts to implement an SMS.

The authorization of the highway bill, SAFETEA-LU, in August 2005, once again placed highway safety at the forefront of government's focus on transportation. Section 148 created a new core safety infrastructure grant program providing for safety conscious planning and data system improvements. Under the new bill, each state must develop a Strategic Highway Safety Plan (SHSP) and implement a Highway Safety Improvement Program (HSIP) that will identify safety problems and opportunities, be data driven, and coordinate with other highway safety programs in the state. The purpose of the HSIP is to identify the state's key safety needs and guide investment decisions to achieve significant reductions in highway fatalities and serious injuries on all public roads. The SHSP must address the four "E's" of highway safety (engineering, education, enforcement, and emergency response). Finally, states are required to evaluate the programs on a regular basis.

SAFETEA-LU requires states to have in place a crash data system with the ability to perform safety problem identification and countermeasure analysis on all public roads. SAFETEA-LU also requires states to advance their capabilities for traffic records data collection, analysis, and integration with other sources of safety data (e.g., state traffic record systems, input from police such as citations, input from emergency service providers and highway maintenance workers, motor carrier data, transit data, the FRA inventory of highway–railroad grade crossings, medical records, crash data research, public meetings, road inventories, and driver records). States should strive to improve the timeliness, accuracy, completeness, uniformity, integration, and accessibility of the safety data needed to identify priorities for federal, state, regional, and local highway and traffic safety programs.

Given the new set of safety data requirements, the current state of safety program coordination and safety data systems, and the HSIP requirements mandated in the SAFETEA-LU reauthorization, highway safety programs are once again at a crossroad. There is an acute need to improve the efficiency of data collection, processing, and evaluation required for successful safety programs at the state and municipal levels. SAFETEA-LU funding levels should provide a good foundation for the changes that need to occur, although many states will require much higher levels of funding to make necessary improvements in data systems. To bridge the gap from system inadequacies to effective safety data, states will have to turn to more efficient and effective technologies to attain a sustainable data collection and maintenance system. This synthesis provides information on new technologies for the acquisition, processing, and overall management of crash, roadway inventory, and traffic operations data.

SYNTHESIS OBJECTIVE

The objective of this synthesis was to summarize the current state-of-the-practice and state-of-the-art use of technologies for efficient and effective collection and maintenance of data for highway safety analysis. Several guiding principles helped to define the scope of the document:

1. Technology is a means by which to overcome many of the limitations found by Pfefer et al. (*5*). Therefore,

safety data systems should benefit from technologies in terms of timeliness, accuracy, completeness, comprehensiveness, efficiency, and integration.
2. Technology alone cannot solve all problems associated with safety data systems, especially those related to a lack of institutional cooperation. Organizational issues should be addressed before considering technological advancements.
3. Technology implementation and maintenance can be capital-intensive, requiring significant funding and programmatic support; benefits and costs must be clearly evident across all affected agencies.
4. Because technologies are constantly evolving, agencies should seek to employ technologies that allow flexibility. In addition, a practical plan for maintaining and upgrading the technologies, as well as assessing their continued effectiveness should be developed before initial investment and implementation of the technology.
5. An array of technologies should be considered because no single technology will allow for the collection and maintenance of the varied databases required for safety analysis.

In light of these principles, this synthesis highlights technologies that have been successfully implemented for the collection, processing, or management of safety-related data with associated benefits as described earlier. Because all state data systems are not the same, an assortment of technology solutions is included—some of which could be used in combination with other technologies or independently depending on specific needs of the state. The document does *not* consider overarching issues related to institutional and financial obstacles associated with crash data system improvements because these have been addressed elsewhere (*2*, *5–11*).

METHODS

A multifaceted approach was used to define data requirements and identify technology solutions to enhance the timeliness, accuracy, efficiency, completeness, comprehensiveness, and integration of safety data sources. The following are six specific focus areas for this report:

- Examine new safety analysis tools to identify data requirements.
- Survey states to determine compliance with identified data requirements (crash, roadway inventory, and traffic operations) and to recognize types of technologies used to collect, process, and manage the three data types, as well as the extent of their use.
- Follow-up with states to ascertain additional information or clarify existing information on technology use.
- Develop a matrix of available technologies to support collection, processing, and maintenance within the three primary data categories.
- Complete a literature search on technologies identified from the survey, general knowledge of the area, and through suggestions from the research review panel.
- Develop a matrix matching technologies to specific data requirements to guide agencies seeking to use new technologies to support safety information systems.

ORGANIZATION OF SYNTHESIS

Chapter two gives a brief overview of the purpose and requirements of the new safety analysis tools, including the IHSDM, SafetyAnalyst, and *HSM*. For existing tools specific data requirements are provided, and for future tools data requirements are generalized based on information obtained from development teams. Additionally, current literature contains numerous references to safety data requirements, data systems, and implementation issues and these are also discussed in this chapter. This chapter provides the framework for the definition of technologies that can be used to satisfy the requirements of the variety of safety analysis tools that exist today, as well as those that will be available in the near future.

Chapter three summarizes findings from each of the three surveys—the crash database survey, road inventory database survey, and traffic operations database survey. In particular, these summaries serve to identify the critical gaps between current and required future data resources. The summaries also highlight technologies that the states are using, and provide limited information on evaluations and implementation issues. The complete surveys and tabulated responses are provided in Appendixes B, C, and D.

Chapter four provides overviews of many of the new technologies currently available to improve data collection and data maintenance activities. These overviews also contain information obtained through the surveys and follow-up—who is using the technology, what does it do, how accurate are the data, what are potential implementation issues, etc.

Chapter five presents a data requirements and technologies matrix for safety data collection. A number of technologies have been identified to satisfy the diverse needs of various safety analysis tools and programs. Given the individual needs of the states, the data and technology matrix will allow the states to identify data needs and determine groups of technologies that are available to increase the timeliness, accuracy, completeness, comprehensiveness, efficiency, and integration of their data sources.

The final chapter, chapter six, provides conclusions and recommendations for further research. Some technologies, such as geographic information systems (GIS) for data processing and management, were identified as critical components for effective safety data systems.

CHAPTER TWO

SAFETY DATA SOURCES, ANALYSIS TOOLS, AND DATA REQUIREMENTS

SAFETY DATA SOURCES

NHTSA (*6*) defines a state traffic records system as:

> [A] virtual system of independent real systems, which collectively form the information base for the management of the highway and traffic safety activities of a state and its local subdivisions. The highway safety information system comprises the hardware, software, personnel, and procedures that capture, store, transmit, analyze, and interpret the data in these separate systems. The core components of this collection of independent systems are the crash, roadway, driver, vehicle, citation/adjudication, and injury control data systems. These are considered as core components because each is intended to represent a census of all the events appropriate to that database; e.g., the crash file contains records of all crashes occurring in the state, the driver file contains records of all drivers licensed in the state, etc. Furthermore, they are essential to provide a comprehensive understanding and quantification of a state's total highway safety problem.

Figure 1 shows an ideal data flow schematic for HSIS (*6*). Ideally, the data sources are systematically designed and connected to share data seamlessly regardless of organizational boundaries. However, these systems actually often operate more like islands of information than collective interconnected systems. Several reports (*5*, *7*, *8*, *14–16*) have been published over the last 15 years detailing the reasons for this disparity and proposing changes in policy, institutional organization, funding, processes, and technologies to resolve the issues. Unfortunately, a number of the same problems identified over a decade ago still exist today.

Many of the issues related to improving state safety data sources must be resolved by stakeholder consensus; however, a great number of the qualitative, quantitative, and logistical challenges can be resolved with technology solutions. There are six clear advantages of implementing new technologies for collecting, processing, and managing safety data:

- Timeliness, affecting how quickly safety data are updated and made available for use;
- Accuracy, referring to how closely recorded data represent truth;
- Completeness, indicating data quality and a requirement for data elements that provide linkages to other data sources;
- Comprehensiveness, which can be associated with a single data element or a data source and relates to whether data are available for a population or only a sample;
- Efficiency, involving easing the burdens of data collection, processing, and storage, as well as limiting duplicative actions and data repositories; and
- Integration, providing interconnections between all of the data sources.

These six advantages are all qualities of the data or system that can be realized using technologies. There are other desirable qualities such as consistency and accessibility that are important, but are more closely aligned with policy and organizational directives than technologies. From a data perspective, consistency may refer to conformity with nationally accepted data standards or uniformity of elements collected by varying reporting jurisdictions. There are several standards and guideline documents that can be referenced for consistency of crash data including:

- Model Minimum Uniform Crash Criteria (MMUCC).
- *Manual on Classification of Motor Vehicle Traffic Accidents*, 6th Ed., ANSI D16.1-1996.
- Data Element Dictionary for Traffic Records Systems, ANSI D20.1-1993.

Similar guidelines are currently under development for roadway and traffic data to accompany those crash data. These efforts are associated with the development of IHSDM, SafetyAnalyst, and the *HSM*.

From a system perspective, accessibility is fundamental to the usefulness of the databases for analysis and supporting decision making. The information in the various databases should be readily and easily accessible to the principal users of the data containing interconnected crash, roadway, traffic, and other information for both direct access and periodic outputs consistent with confidentiality requirements. In today's highly networked society, the ability to share data is hindered primarily by institutional issues.

Referring back to Figure 1, there are six main types of data in a safety information system:

- Crash information,
- Roadway information,
- Vehicle information,
- Driver information,
- Citation/adjudication information, and
- Injury control information.

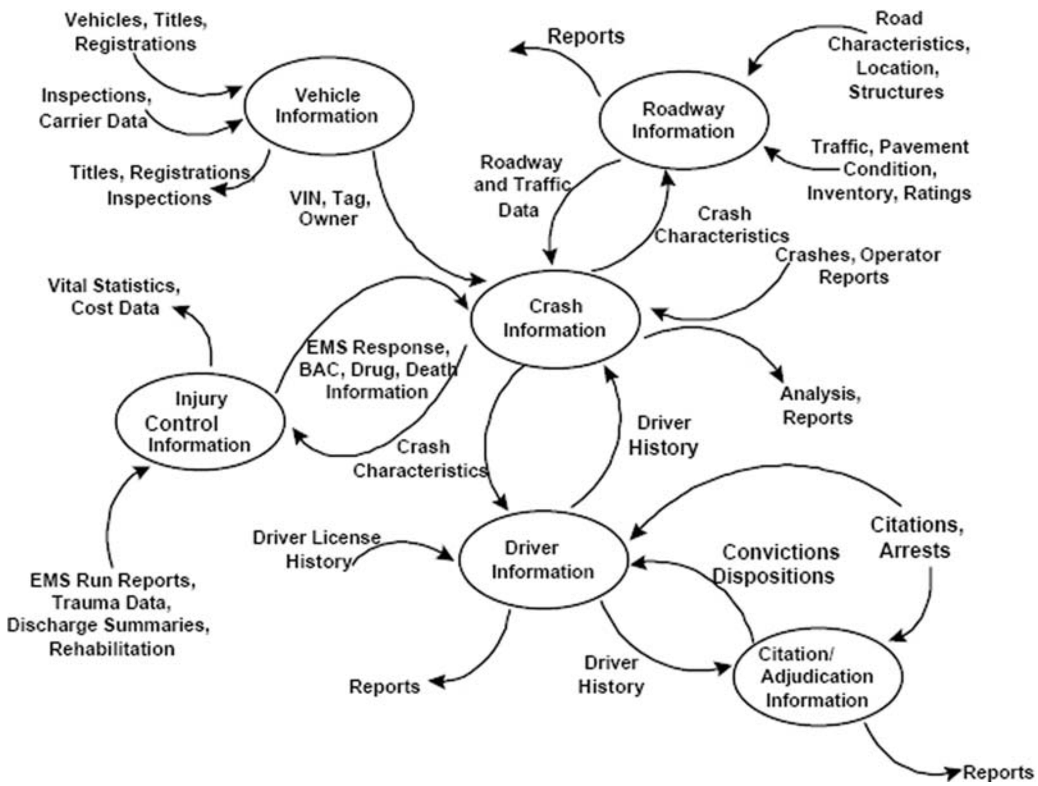


FIGURE 1 Data flow schematic for Highway Safety Information Systems (*6*).

The focus of this report is on the crash and roadway data types. However, many of the technologies—especially those related to crash reporting—have positive implications for data collection and provision of linkages to the other data types. For example, technologies that connect to tablet or laptop computers used for electronic crash reporting in the field (i.e., barcode scanners and magnet strip readers) allow officers to capture driver's license and vehicle registration information and automatically populate driver and vehicle information fields. This form of automation significantly reduces the chances of coding and keying errors that limit linkages between the crash, vehicle, and driver information sources.

Figure 1 also shows that roadway information is a combination of (1) road characteristic, location, and structures and (2) traffic, pavement conditions, and ratings. For purposes of clarity, this document distinguishes between the two types of roadway information and presents roadway characteristic inventory information and traffic operations information separately. All three primary data categories are defined here.

Crash Data

Crash data describe the events, vehicles, and persons involved in a crash. The general characteristics of the crash include the date, time, location, drivers, occupants, and vehicles involved. Other descriptive categories are severity of the crash (whether the crash ended in property damage only, an injury, or a fatality) and the type of collision (right angle, rear end, and sideswipe). The conditions of the roadway surface and of traffic control devices are also important aspects of crash data. According to the NHTSA Traffic Records Advisory (*6*), crash record systems should contain at least minimal information for every reportable motor vehicle crash on any public roadway in the state. In addition to providing information on a particular crash, a crash database supports analysis of crash trends as well as analysis of crashes within specific categories defined by person, location, or vehicle characteristics. Researchers and practitioners conduct crash data analyses to identify safety problems, evaluate solutions, and provide direction for highway safety programs.

Roadway Inventory Data

A roadway inventory system is a collection of roadway characteristic data. It includes a list of the roads, along with roadway location, identification, and classification. Additionally, the inventory contains a physical description of the roadway components, such as number of lanes, lane width, presence of medians and shoulders, and type and presence of roadside barriers. Photograph/video-log data may also be a part of the roadway inventory. According to the NHTSA Traffic Records Advisory (*6*), roadway inventory data should be available for all public roads in the state under state or local jurisdiction. Incorporation of GIS and a linear reference system allows roadway inventory data to be referenced spatially and linked with other information sources for analytical purposes.

Traffic Operations Data

Traffic operations data are information gathered about traffic conditions on the roadways. It may be collected manually or by means of automatic traffic recorders. In general, it encompasses all of the traffic data collected for HPMS and from advanced traffic management operations. The HPMS is a database that represents a selected sampling of data to fulfill federal requirements. These data depict exposure levels for sampled roadways and are required by FHWA for the development of national statistics and for allocating funding resources. Data from the traffic operations category includes traffic volumes, intersection turning movements, speed measurements, and vehicle classifications. Traffic control devices, pavement markings, retroreflectivity, and sign inventories are other aspects of traffic operations data.

Together, the data sources provide information about the roads, people, and vehicles involved in crashes and about the factors that may have contributed to the incident. However, additional sources of data may also be required to control for differences in demographic characteristics or exposure levels of subsamples of the population. Cost information is also considered an essential ingredient for cost–benefit evaluation of safety-related countermeasure programs.

SAFETY ANALYSIS TOOLS

Within SAFETEA-LU, there are new requirements for comprehensive HSIPs that are *data-driven* and encompass all public roadways. Given these requirements, states will likely turn to the new FHWA analysis tools to achieve better quality safety analysis and comprehensive prioritization of safety problems. Of the three safety analysis tools (IHSDM, SafetyAnalyst, and *HSM*), only the IHSDM has been released for public use. The other two safety analysis tools are still under development, with initial releases expected within one to two years. The tools are intended to provide users with a variety of safety analysis options. Furthermore, the tools have been designed to complement one another rather than duplicate or contradict one another. The following sections provide information on the purpose of the safety analysis tools and provide an introduction to the analysis components and resulting output.

Interactive Highway Safety Design Model

The IHSDM is a suite of software analysis tools for evaluating safety and operational effects of geometric design decisions on two-lane rural highways. As a decision-support tool, it checks existing or proposed two-lane rural highway designs against relevant design policy values and provides estimates of a design's expected safety and operational performance. The results support decision making in the highway design process.

IHSDM currently includes five evaluation modules:

- The Crash Prediction Module estimates the expected frequency of crashes on a highway using geometric design and traffic characteristics.
- The Design Consistency Module estimates the magnitude of potential speed inconsistencies to help identify and diagnose safety concerns at horizontal curves.
- The Intersection Review Module performs a diagnostic review to systematically evaluate an intersection design for typical safety concerns.
- The Policy Review Module checks highway segment design elements relative to design policy.
- The Traffic Analysis Module estimates operational quality-of-service measures for a highway under current or projected future traffic flows.

A sixth evaluation module, the Driver/Vehicle Module, which estimates a driver's speed and path along a highway and corresponding measures of vehicle dynamics, is under development.

The IHSDM supports safety analysis of specific two-lane road sections or corridors. The module output allows direct comparisons of safety implications between alternative designs for the same roadway section or corridor. Much of the highway segment geometry data required by IHSDM are generated during the design process within the civil design software packages. With the objective of minimizing the effort required to export data from these packages and import it to IHSDM, FHWA cooperated with civil design software vendors to develop mechanisms for data exchange. The following software packages are currently supported:

- GEOPAK data can be extracted using a GEOPAK-to-IHSDM Data Extractor.
- CAiCE data can be extracted using CAiCE's IHSDM Toolbox in LandXML format within Visual Roads.
- LandXML data exported by other civil engineering design software packages can also be imported into IHSDM.

Alternatively, in the absence of electronic plan/profile information (as is the case for many existing roadways), IHSDM allows direct entry of geometry data within the software package. In this case, design data can be taken from hard-copy plan sheets. Additional information, as well as the IHSDM software, may be obtained from the website at http://www.ihsdm.org.

SafetyAnalyst

SafetyAnalyst is a set of software tools being developed for use by state and local highway agencies to improve their programming of site-specific highway safety improvements. SafetyAnalyst will address site-specific safety improvements that involve physical modifications to the highway system. It is *not* intended for direct application to non-site-specific highway safety programs that can improve safety for all highway travel, such as vehicle design improvements, graduated licensing, occupant restraints, or alcohol and drug use programs. However, SafetyAnalyst will have the capability not only to identify accident patterns at specific locations and determine whether those accident types are overrepresented, but also to determine the frequency and percentage of particular accident types system-wide or for specified portions of the system (particular highway segment or intersection types). This capability can be used to investigate the need for system-wide engineering improvements (e.g., shoulder rumble strips on freeways) and for enforcement and public education efforts that may be effective in situations where engineering countermeasures are not. SafetyAnalyst is comprised of six tools:

- The Network Screening Tool will identify "sites with promise" for safety improvements.
- The Diagnosis Tool will be used to diagnose the nature of safety problems at specific sites.
- The Countermeasure Selection Tool will assist users in the selection of countermeasures to reduce accident frequency and severity at specific sites.
- The Economic Appraisal Tool will perform an economic appraisal of a specific countermeasure or several alternative countermeasures for a specific site.
- The Priority Ranking Tool will provide a priority ranking of sites and proposed improvement projects based on the benefit and cost estimates determined by the economic appraisal tool.
- The Evaluation Tool will provide the capability to conduct before and after evaluations of implemented safety improvement projects.

SafetyAnalyst will be capable of using data from existing highway agency data files, and will also be capable of using data from AASHTO's planned Transportation Safety Information Management System (TSIMS). Unlike the IHSDM software, which operates on data for single corridors, SafetyAnalyst requires area-wide or statewide data inputs. Therefore, the level of detail of the geometric data required for SafetyAnalyst is far less than that required by IHSDM. On the other hand, SafetyAnalyst requires far more crash data and general road inventory data. For more information and future software downloads, SafetyAnalyst can be found online at http://www.safetyanalyst.org.

Highway Safety Manual

The purpose of a *HSM* is to provide practitioners with the best factual information and tools to facilitate roadway design and operational decisions based on explicit consideration of their safety consequences. Currently, there are no such widely accepted tools available for agencies responsible for managing the safety of our roadways. As a result, safety considerations often carry little weight in the project development process. When difficult choices must be made, greater confidence is often taken in predictions of such factors as cost, operational impacts, and environmental impacts that are supported by a number of software tools and prediction models. The *Highway Safety Manual* will be an effective resource that can be used to quantify and predict the safety performance of the variety of elements considered in road planning, design, maintenance, construction, and operation. The first version of the *HSM* is anticipated to be released in 2008. More information on the development of the *HSM* can be found at http://www.highwaysafetymanual.org.

The development of all of the safety data analysis tools will significantly influence the ability to use safety data for decision making. However, the ability to analyze and use data is limited if the data are not available. Thus, the development of these safety tools is essentially driving the need for safety data. The remainder of this chapter focuses on the data requirements generated by the use of the three safety analysis tools. Subsequent chapters will discuss current data collection trends among states with respect to the impending data needs, as well as identification of new technologies to support collection, processing, and management of safety data.

SAFETY DATA REQUIREMENTS

Before delving into the data requirements for the safety analysis tools, it is important to note that at the time this document was written, all of the tools were still in some stage of development. Therefore, readers should use the following information with caution, noting that the data requirements may be somewhat dynamic. For example, the currently available version of IHSDM only considers safety analysis for two-lane rural roads. When the urban multi-lane updates are available for the IHSDM, the listing of geometric design elements will most certainly change. The most obvious changes include the requirement for the number of lanes and area type, where previously in the rural two-lane version the number of lanes and area type is inherent.

For all intents and purposes, the number and detail of required data elements is only expected to increase in the near future. The NCHRP Project 17-25 (Crash Reduction Factors for Traffic Engineering and ITS Improvements) team was tasked to develop the knowledge base from which the initial edition of the *HSM* will be developed. After reviewing hundreds of reports and journal articles representing more than 100 safety treatments, only 21 treatments passed the required thresholds for research quality and allowable error. These findings indicate that much more research will need to be conducted. In the meantime, researchers do not know what other elements may be found to be significant in prediction of the safety of our roadways. In many ways, this determination is limited to data that can be obtained.

As previously described, the safety analysis tools are very different in their purpose and scope, which greatly affects data requirements. Practitioners use IHSDM to analyze a specific section of roadway and therefore the program requires very detailed geometric design data along with minimal traffic operations and crash data, whereas, SafetyAnalyst is a more global analysis tool that can be used to analyze and priority rank area-wide intersections and road segments based on predicted crashes across a wide array of functional classes and design variables. SafetyAnalyst thus requires extensive crash data, roadway inventory data, and traffic data for area-wide or statewide applications. SafetyAnalyst requires only limited geometric data. Presently, there is very little overlap between the data requirements of the two tools. The following sections provide a brief overview of the required data elements. Specific detailed information regarding the IHSDM data requirements can be found online at http://www.ihsdm.org following links to Documentation, IHSDM User Documentation Summary, and Highway Model User's Manual. Similar online documentation is not currently available for SafetyAnalyst, but was expected to become available with the public release of the software in 2006.

Both IHSDM and SafetyAnalyst use three types of data: roadway inventory (geometric) data, traffic operations data, and crash data. The level of detail among the data types varies significantly between packages. Both packages offer separate analysis for intersections and road segments; therefore, within the following data requirements lists, intersections elements are cited individually.

Interactive Highway Safety Design Model Data Requirements

One of the first steps involved with using IHSDM is to compile data describing the highway under evaluation. This may be accomplished manually by extracting design details from existing plan/profile sheets and entering them directly into the software using preexisting electronic design files, collecting new survey data and entering it manually, or by developing new design files for export. In addition to the geometric design data requirements, the IHSDM software requires speed and volume information for the roadway analysis section. Crash data are only required if there are plans to calibrate the crash prediction module to achieve more effective estimates of the crash predictions; however, the module can be run without it. The exact data requirements depend on which program module(s) will be executed and the ultimate usage of the output information.

Road Inventory (Geometric) Data

Horizontal alignment elements include:

- Horizontal tangent—heading and length,
- Horizontal simple curve—radius and position,
- Horizontal spiral curve—presence and position, and
- Horizontal deflection—angle and direction.

Vertical alignment elements include:

- Vertical point of intersection—back grade, back length, forward length;
- Vertical tangent—position and length;
- Vertical curve—position and length; and
- Elevations.

Cross-section elements include:

- Highway cross slope—normal crown and superelevation;
- Pavement type; and
- Shoulder—type, slope, side, and rounding.

Lane elements include:

- Thru lane—number and width;
- Auxiliary lane—passing, turning, two-way left-turn, or climbing;
- Lane offset; and
- Curve widening.

Roadside elements include:

- Foreslope—slope and width;
- Backslope—slope and width;
- Ditch—bottom shape and width;
- Obstruction—offset, presence, and side;
- Bike facilities—presence and side;
- Driveway density; and
- Roadside hazard rating.

Intersection elements include:

- Number of intersection legs,
- Type of traffic control,
- Approach type—major leg/minor leg,
- Intersection skew angle,
- Number of major road approaches with exclusive left-turn lanes,
- Number of major road approaches with exclusive right-turn lanes, and
- Number of intersection quadrants with limited intersection sight distance.

Traffic Operations Data

The required traffic volume data can be divided into two categories: the highway segment traffic volume data and the intersection traffic volume data. Typical elements include:

- Terrain;
- Functional classification;

- Speed—design, 85th, and posted; and
- Volume—average daily traffic (ADT), design hourly volume, and peak hour.

Crash Data

In IHSDM, the use of actual crash history data is optional, but desirable, to improve the overall crash prediction estimates from the Crash Prediction Module. Values for the following variables are needed when historical crash data are used:

- Crash year;
- Severity—fatal/injury or property-damage only;
- Location; and
- Relation to intersection—related or nonrelated, entry, and exit legs.

SafetyAnalyst Data Requirements

Much like the data requirements for IHSDM, the requirements for SafetyAnalyst are also separated into intersection and roadway segment components. Recall that SafetyAnalyst is used to analyze crashes comprehensively for statewide or area-wide safety estimates. Therefore, the population of roadways would be included. The comprehensive analysis approach requires a strict intersection and segment identification system; therefore, there are a number of required variables relating to intersection and segment numbers and intersection and segment location. In addition, ramps are also treated as separate analysis entities. The following list of elements contains mandatory data elements as well as optional data elements. Optional elements are denoted with an asterisk (*)—these elements are desirable and will be used by SafetyAnalyst when available.

Road Inventory (*Geometric*) *Data*

General elements include:

- Segment number,
- Route type,
- Route name or number,
- County number,
- Roadway segment location,
- Highway system code,
- Segment length,
- District number,*
- City/town number,*
- Jurisdiction,*
- Area type, and
- Date opened to traffic.*

Cross-section elements include:

- Thru lanes—number (dir) and width,*
- Auxiliary lanes—number (dir),*
- Median—type and width,* and
- Shoulder—type and width.*

Roadside elements include:

- Bike facilities—presence and
- Driveway density.*

Intersection elements include:

- Intersection location,
- Type of intersection,
- Type of traffic control,
- Major road direction,
- Influence zone—beginning and end,
- Offset intersection—presence and distance,
- Intersection leg
  - Direction
  - Number of lanes—thru, right-turn, left-turn
  - Median type
  - Signal—left-turn phasing
  - Turn prohibitions.

Ramp elements include:

- Ramp number;
- Ramp—location, type, configuration;
- Type of connection—at freeway and crossroad;
- Number of lanes; and
- Volume—ADT.

Traffic Operations Data

- Terrain;*
- Functional class—Level 1, 2,* and 3;*
- Speed—posted;*
- Volume—ADT, design hourly volume,* peak hour,* growth factor,* percentage of heavy vehicles;*
- Access control;*
- Traffic-way flow; and
- Interchange influence area.*

Crash Data

Unlike IHSDM, SafetyAnalyst requires extensive crash data. There are three categories of accident-related variables in the master database: accident-level data elements, vehicle-level data elements, and person-level data elements. The following list of elements contains mandatory data elements as well as optional data elements. Optional elements are denoted with an asterisk (*)—these elements are desirable and will be used by SafetyAnalyst when available. Additionally, many of the elements either conform to MMUCC (denoted by M) or are similar to MMUCC elements (denoted by SM).

Accident-level crash data elements include:

- Accident case identifier (M),
- Route type,
- Route name/number,
- County number (M),
- Accident location (SM),
- Location identifier system,
- District number,*
- City/town number* (M),
- Accident date (SM),
- Accident time (SM),
- Relationship to junction (SM),
- Driveway indicator,*
- Light condition* (M),
- Weather condition* (M),
- Roadway surface condition* (M),
- Accident type and manner of collision (SM),
- Contributing circumstances—environment* (M) and road* (M),
- School bus related (M),
- Work zone related (SM),
- Number of vehicles involved (M),
- Accident severity (M),
- Alcohol/drug involvement* (M),
- Tow-away indicator,*
- Run-off road indicator,*
- Pedestrian indicator,*
- Bicycle indicator,*
- Divided highway flag,* and
- Day of week (M).

Vehicle-level crash data elements include:

- Initial direction of travel (M),
- Vehicle maneuver/action (M),
- Vehicle configuration (M), and
- First harmful event (M).

The only person-level crash data elements currently used by SafetyAnalyst are the driver age (SM). Because driver age can be attributed to a single vehicle, it could be combined with vehicle-level data elements.

Appendix A includes a complete listing of elements from both software packages indicating the overlap between the packages. As noted previously, this listing provides the best available information given the associated levels of development of the individual packages. Additional guidance is expected to be developed by NCHRP in conjunction with the 500 Series of reports, which is a set of guides to assist state and local agencies in reducing injuries and fatalities in targeted emphasis areas. The guides correspond to the emphasis areas outlined in the AASHTO Strategic Highway Safety Plan. The data guide would provide specific data requirements and formats for use in analysis to support the implementation of the 500 Series recommendations. The Highway Safety Manual Task Force is also considering the development of Minimum Inventory of Roadway Elements, which would be similar to MMUCC for crash data.

CHAPTER THREE

STATE OF THE PRACTICE

The objective of this synthesis project is to summarize the state-of-the-practice and state-of-the-art utilization of technologies for improving safety data. One critical source of information for the synthesis came from a survey of state agencies. The surveys provided information not only on successful uses of technology, but also helped to identify critical gaps in technologies for acquiring, processing, and maintaining safety data.

The survey design was significantly complicated by the number and breadth of data collection and maintenance activities undertaken by each of the surveyed agencies. Owing to the breadth of the survey content, three different surveys were developed and distributed to contacts in each state for each of the three core safety data areas (crash, roadway inventory, and traffic operations). The survey design included a set of 12 general database questions followed by a varying number of specific data and technology-related items specific to the type of database in question. The three surveys can be found in Appendixes C, D, and E. The roadway inventory survey (see Appendix D) contained elements related to both roadway inventory and pavement management, whereas the traffic operations survey (see Appendix E) covered Advanced Traffic Management Systems and traffic operations. Even though specific surveys were not distributed to obtain information for citations and convictions, emergency medical services, and medical, driver licensing, and vehicle registration databases, information regarding such databases was included with the responses from states using electronic crash records systems. In total, approximately 60 surveys from 34 states were received out of the total of 150 that were distributed.

CRASH RECORD DATABASE SURVEY RESPONSES

Crash report data are compiled for most crashes that involve fatalities, injuries, and property damage above specific state thresholds. Items of general interest include location, date, and time of crash; driver information including age, gender, and license; vehicle information including year, make, model, and registration; and environmental elements such as road design features, traffic controls, and weather. Responses to the crash survey were received from 24 states: Arizona, Arkansas, California, Connecticut, Delaware, Georgia, Illinois, Iowa, Maryland, Michigan, Missouri, Nevada, New Hampshire, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, Texas, Utah, Washington, West Virginia, Wisconsin, and Wyoming. Figure 2 shows the geographic distribution of responding state agencies. Respondents from Departments of Public Safety or other Patrol Agency were nearly half (11 of 24) and the remainder (13 of 24) were from DOTs. A summary of survey responses follows.

It is not surprising that the majority of state crash records custodians are active in statewide safety initiatives. Of 24 responding states, 21 have a Traffic Records Coordinating Committee and 11 are also involved in a Safety Management System. Three states did not indicate involvement in either of these initiatives. Two states indicated that they were also Crash Outcome Data Evaluation System (CODES) states.

Acquisition

All 24 states use paper-based forms to report crashes. Of these, 17 also use some type of electronic form in conjunction with a portable computer, and 3 of the 17 include electronic data obtained from event data recorders (automobile blackbox). Six states, Arkansas, Delaware, Iowa, Maryland, North Dakota, and Wisconsin, use Traffic and Criminal Software (TraCS) as the electronic software for crash record capture, and the remaining 11 states use other electronic crash report software. Of the 17 states that indicated collecting electronic crash records, 10 responded to the question regarding the percentage of total crash records captured electronically. One-half (5 of 10) reported that they capture less than 10% electronically, one stated approximately 30%, and the remaining four capture more than 60%. The two states capturing the most electronic reports are Nevada and Delaware with 75% and 85% captured, respectively.

A minority of states reported the use of various technologies to support crash data collection. Two states use the magnetic strip reader to record information from a driver's license/registration, and seven states use a barcode reader to obtain data from a driver's license/registration or vehicle identification number (VIN). Laser-based measurements of crash sites are used by three states, and video recording is used by six. Digital photography is in use in nine states, whereas aerial photography is only used in one. Wisconsin

FIGURE 2 Geographic distribution of states responding to crash survey.

uses all of these technologies except the magnetic strip reader. The distribution of technology use for crash reporting can be found in Figure 3.

Most states use multiple methods of locating crashes. The most popular method is the text description, including street name and number and offset to closest cross street. The text description is used by 19 of 23 responding states. Alternative methods supplement the text descriptions in all but three states, where they are used as the primary methods. The alternative methods include grid coordinates taken from map systems (electronic or paper), latitude and longitude coordinates taken from GPS receivers (handheld or in-vehicle), and linear references to route/milepost/reference marker systems. In the absence of data from one of the coordinate/reference systems, text descriptions are used to locate crashes post hoc using a linear referencing system. The distribution of location data formats is provided in Figure 4.

For severe crashes and special studies, several states (including California, Delaware, Iowa, Maryland, Missouri, New Hampshire, and Oregon) employ a variety of tools in addition to the technologies used for regular crash investigations. For example, Delaware's Fatal Accident Investigation and Reconstruction officers use laser management techniques and digital photography to record crash site measurements and crash details. Specialized crash reconstruction teams in Maryland and Oregon measure crash sites using survey-grade technologies. Most states indicated that data obtained for special studies are not included in general crash databases; rather, these are often filed in hard-copy format with the fatal crash reports.

One last question regarding data collection referred to the types of training provided to police officers who collect crash record data. In most cases, officers receive 4–8 h of crash record training at the police academy. On-the-job or in-service training is utilized by some states. The state DOT or the state police department can organize this type of training. Most states provide an accident-reporting guide, which can be used by officers in the absence of or supplemental to organized training courses. Safety conferences and the Institute of Police Training are also sources for crash reporting education.

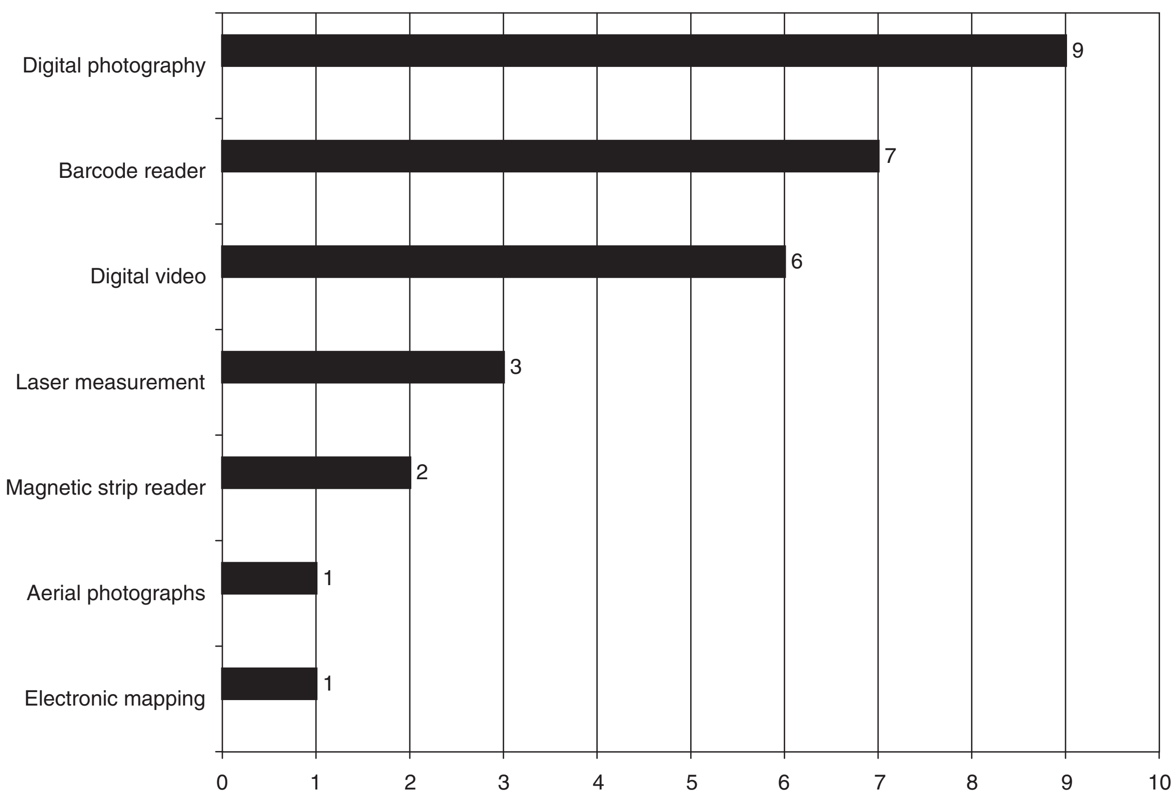


FIGURE 3 Reported technology use for crash data collection.

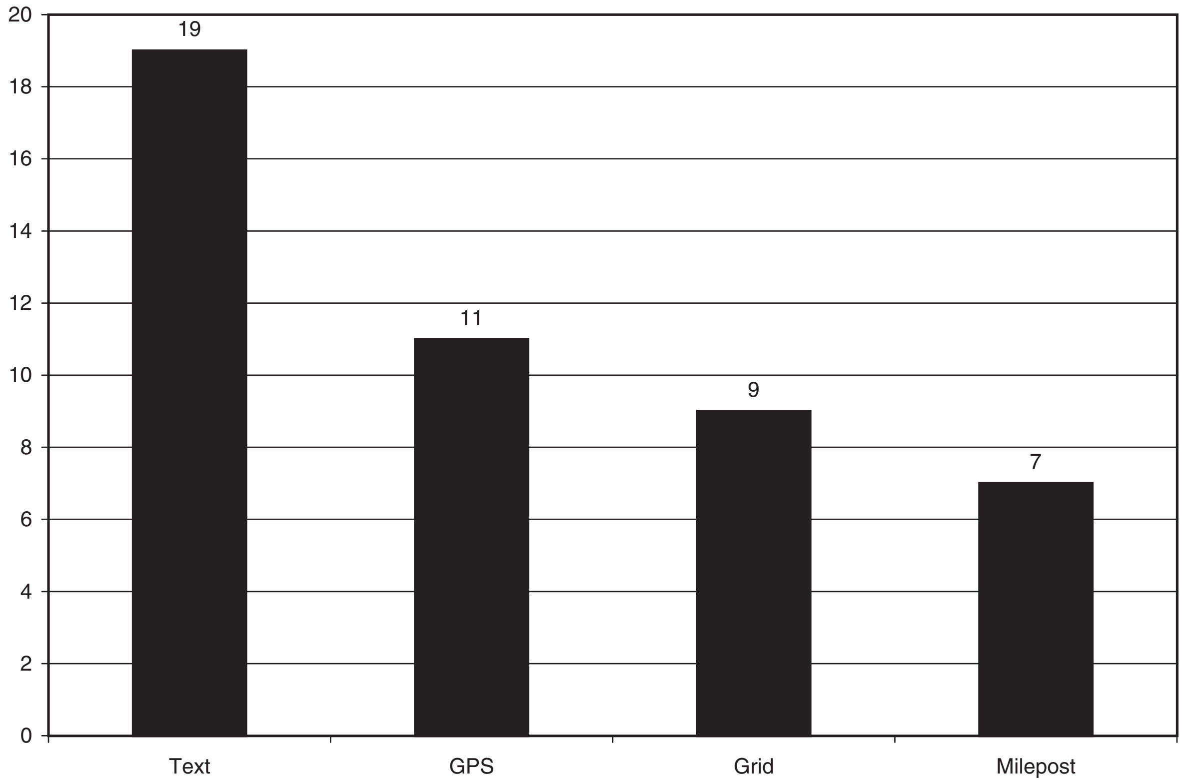


FIGURE 4 Distribution of crash location data format.

Processing

All of the responding states maintain crash record data at a centralized state repository. Nine states also indicated that data are maintained at the jurisdictional or local level. Only one-third of the states that indicated maintaining crash record data at lower levels reported data sharing with the central repository.

Currently, 10 of 24 states indicated acceptance of electronic crash record transmission to the central repository, and 3 other states are in the process of implementing electronic transmission and receipt systems. All responding states indicated receipt of crash records in hard-copy format. Original hard-copy crash report forms are maintained in four states; one of the four scans the original to microfilm and another scans to a digital image file. In total, 15 states scan crash reports to digital image files, whereas 4 states still use microfilm technology.

Eighteen of the 24 responding states have crash records databases that contain specific data elements that allow linkage to other databases. The distribution of linkages between crash records and other data sources is shown in Figure 5. Additional linkages were reported between crash records and hospital, bridge, and pavement records. Challenges or obstacles to data linkage include a lack of accuracy and exactness of data, amount of data entry time, a lack of necessary technologies, out-of-date storage devices (i.e., mainframes and tape systems), inadequate information technology staff support time, inadequate technical support and knowledge, and connectivity issues between database platforms.

Storage and Maintenance

In terms of data storage, the majority of the 21 responding states use Oracle (7, 33%), SQL (7, 33%), or DB2 (9, 43%) databases. Most states in transition indicated moving toward Oracle and SQL solutions. Some of these states also maintain mainframe systems—presumably for maintaining legacy data. Several states responding to the survey, however, still use mainframe systems as their primary data storage system.

Access to crash records data is provided to users within the custodial agency in each of the 23 responding states. Fifteen states provide access to other state agencies, and 12 provide access to local agencies. Access is provided in a number of formats. The most common format for intra-agency use is a secure intranet site. External access is provided through secure Internet sites, unsecured Internet sites, FTP transfers, CD-ROM/DVD, e-mail, and hard copy.

Crash Record Database Survey Summary

All states maintain crash records in a centralized location to fulfill reporting requirements mandated at the federal level. However, a number of states indicated that redundant data repositories were maintained by local jurisdictions. A few

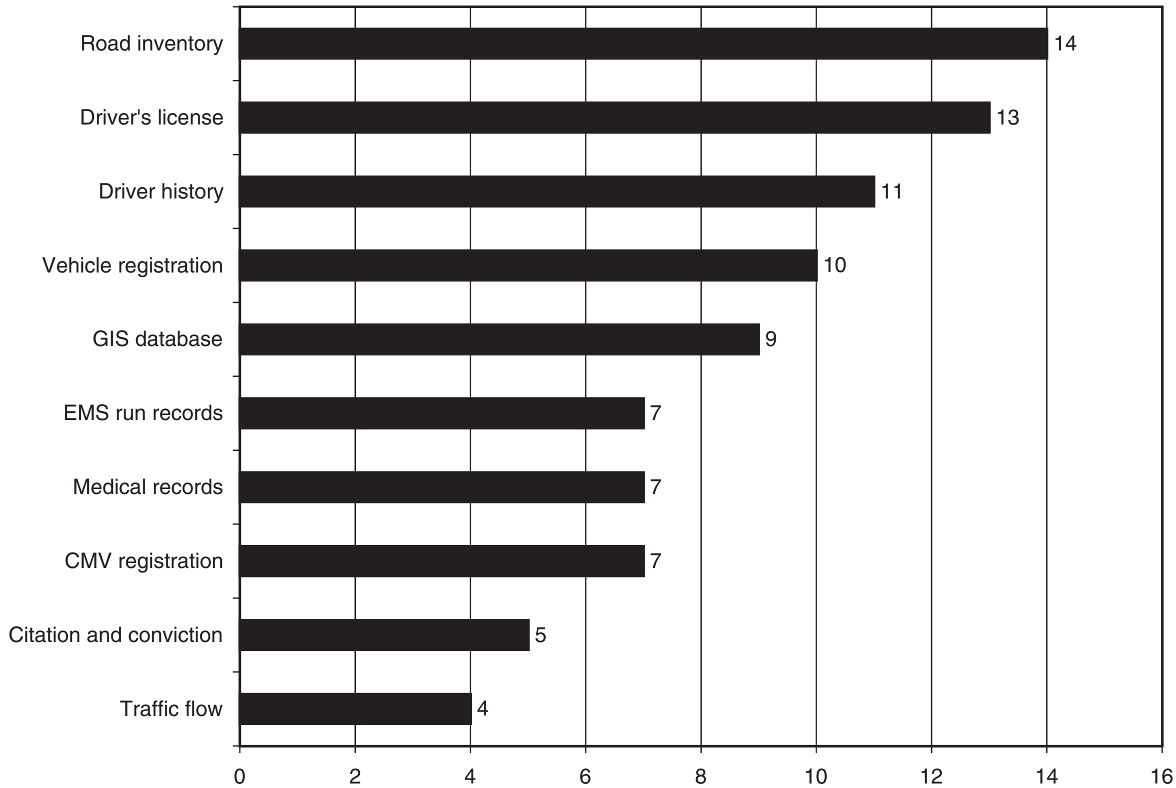


FIGURE 5 Reported linkages from crash records database survey (24 respondents). CMV = commercial motor vehicle; EMS = emergency medical services.

states noted that this occurrence was the result of strict data protections required by the state agency. Limited data sharing is occurring from a centralized crash database to other state agencies and local agencies.

The survey of states indicated that the use of technologies for collecting data was limited, and so too were efforts to research new methods for data collection and maintenance. Although a number of states reported the capture of electronic crash reports, few had widespread use throughout the state. A number of technologies exist within these electronic reporting systems; however, these too are not employed extensively. When technologies are used for special studies (i.e., laser or survey grade measurement and digital photography), much of the data is filed away in hard copy, limiting its long-term usefulness.

Many states still use route and milepost linear referencing systems. States that have been moving toward linked crash records systems have discovered the usefulness of moving toward link node reference systems. In link node systems, links can be retired yet maintained with new ones without losing the ability to link the historical road characteristics records with historical crash data. Of the three main data components, crash records and road inventory are reported as being linked far more often then crash and traffic flow databases.

A few states indicated that they were still using mainframe legacy systems for crash records storage and maintenance, which severely limits their ability to perform analysis and link to other data sources. Several states indicated their frustration with the lack of funding available for obtaining technical support, new technologies for crash data collection, and updating data storage devices.

ROAD INVENTORY DATABASE SURVEY RESPONSES

Roadway inventory data include the physical features within a road's right-of-way. These data include geometric data, cross-sectional elements, traffic control devices, and pavement-related data. All state highway agencies are responsible for collecting, processing, managing, and analyzing roadway inventory data. The primary uses of these data are for federal reporting, planning, and design. The survey of states indicated that roughly half of those that responded to the survey use roadway inventory data for input to safety evaluation. Responses to the survey were received from 20 state DOTs: Arkansas, Colorado, Florida, Georgia, Hawaii, Idaho, Illinois, Iowa, Massachusetts, Minnesota, Mississippi, Missouri, Oklahoma, Oregon, South Carolina, South Dakota, Tennessee, Texas, Washington, and Wisconsin. The geographical distribution of responding states is shown in Figure 6. A summary of the survey responses follows.

Unlike the responses from the crash records survey, fewer than half (9 of 20) of the respondents are involved with a Traffic Records Coordinating Committee; a similar number

FIGURE 6 Geographical distribution of states responding to the road inventory survey.

(8 of 20) are involved with Safety Management Systems. However, several other safety initiatives were provided by respondents including 402 program initiatives, Local Community Traffic Safety Teams, Toward Zero Deaths Committee, Highway Safety Committee, and Hazard Elimination Safety Program.

Acquisition

The survey of state DOTs included approximately a dozen questions related to data acquisition. The survey indicated that most roadway inventory data is collected in the districts or by headquarters staff dedicated to this function. Sixteen respondents indicated that the data are maintained at a central state repository, whereas four states reported that the data are maintained in district or local repositories. Respondents stated that data maintained at district and local levels are shared with a central database.

The vast majority of the states indicated that they do not participate in research efforts related to improving data collection technology. Fifteen states reported that they plan to deploy new technologies over the next 5 to 10 years, including video-logging, high-speed data collection, more extensive GPS usage, web applications, and road profiling.

The timeliness of data varied greatly depending on what was being collected. All of the states conduct bridge inspections on a two-year cycle. This is not surprising because the inspections are required every two years by federal mandate. Also, the procedures for conducting bridge inspections are standardized. Many states collect road inventory data on an annual basis for some characteristics, whereas a complete reinventory usually approaches 3 to 5 years. Several states had no set schedule, and one state indicated that it never does a reinventory.

Table 1 provides information on collection samples for several categories of road characteristics data for limited access roadways for 18 of the 20 responding states. The table indicates how many states collect data comprehensively, versus sampling or collecting data on an as-needed basis. Similar data collection samples are used for arterial roadways, whereas data for collector and local roads showed less comprehensive coverage with more sampling and as-needed data collection activities.

For geometry data, several states (7 of 20) extract these data from as-built or construction plans. Seven states also indicated that they use sensor technology to collect certain attributes such as roadway grades or cross slope. Some data, such as horizontal and vertical curve information, is collected by post-processing raw spatial data, which is discussed in the next section. Five states use video-log, two use pen and paper, and two others do not collect geometry data.

Road pavement data are collected annually on average. The survey indicated that many states had a great deal of automation in collecting pavement data for the state's pavement management function. Over half of the states reported that they used specialized vans to collect pavement data [six Automotive Road Analyzer (ARAN), one Mandli, and four custom-developed]. The survey responses noted that data collection is somewhat subjective for pavement distress data. Other measurements such as rutting depth, skid resistance, and structural strength are usually made with precise measuring devices. Some states collect these data continuously, whereas others collect the data as a sample (e.g., the first 500 ft of every mile). The survey indicated that pavement data were collected by both in-house staff and by contractors.

The survey responses for data collection of cross-sectional elements such as barriers and clear zone maintenance were sporadic. Four states indicated that they have an extensive video-logging program for this. Others do field surveys using pen and paper and four stated that they do not collect these data. Much of this information would not be available digitally for most of the states with the exception of shoulder width and scanned as-built plans. The responses for sign and pavement inventories were similar to those for other cross-sectional elements. Most states relied on video-logs or as-built plans. Colorado and Washington noted that they use GPS technology for their sign inventory and add attributes. Only four states mentioned that they employ inventory sign retroreflectivity. The same four states indicated that they also collect pavement-marking retroreflectivity. Retroreflectivity values do not appear in a central database.

Processing

State DOTs use data processing for all of the areas listed previously. Processing of the data is required to calculate different performance indicators such as distress, skid, or rutting indices for pavements. Specialized software such as AASHTOWare (e.g., Trns*port, RoadWare, and BridgeWare) allows various functions including construction and maintenance, contract, bridge, and pavement management.

All of the states that were surveyed have some level of GIS use. Florida indicated that it is able to estimate horizontal

TABLE 1
ROAD CHARACTERISTICS DATA AND COLLECTION SAMPLE

Road Characteristics Data	Collect Comprehensively	Sample	As-Needed
Cross-Section Elements			
Number of lanes	17		
Lane width	17	1	
Lane type	15		
Shoulder width	17		
Shoulder type	17		
Edge treatments (SafetyEdge)	2		1
Median width	17		
Median type	17		
ROW width	7		1
Cross slope (normal crown)	4		
Barriers (type, length)	9	1	
Roadway Structure Elements			
Bridges	18		
Railroad crossings	16		
Multi-use paths/bike paths	7	1	
Pedestrian facilities	2	1	2
Tunnels			
Geometric Elements			
Grade	8	8	
Vertical curvature	7	6	
Horizontal curvature	9	6	
Superelevation	3	1	1
Sight distance	2	7	2
Speed limit	15	1	
Sign inventory	4		
Truck/weight restrictions	6		
Intersection Elements			
Number of lanes/approach	1	2	5
Signal timing	1	6	2
Traffic control	5	4	1
Pavement Elements			
Pavement material	15		
Pavement distress data	10	1	
Skid resistance	6		1
Ride quality	12	2	
Pavement markings	1		2

Note: ROW = right-of-way.

curvature with their GIS application by processing centerline data. The GIS can establish the location of the point of curvature and point of tangency, as well as calculate a variety of curve parameters including the length of curve and the radius. Massachusetts indicated a similar capability, and also mentioned that it estimates vertical alignment data using their GIS to drape centerline information over a digital terrain model. Neither state provided information regarding the accuracy of the data obtained from these procedures.

Storage and Management

The survey of state DOTs incorporated several questions with regard to the storage and management of roadway inventory data. Of the states surveyed, 80% have state repositories that are accessible relational databases. Many states (70%) indicated that they have electronic transmission capability to the central repository, but an even greater proportion (75%) noted that they still rely heavily on hard-copy submission of at least some road data inventory items. Most of the original hard-copy data are archived. All states indicated that data are checked using either manual or automated checks. States make data readily available; however, the method varies—70% of the states make data available through the intranet, but some rely on FTP transfer, e-mail, and CD-ROM/DVD. Roughly half of the states with intranet data availability make their data available externally through secured or nonsecured Internet. Most externally available data are aggregated and available only at interval releases—usually annually.

The timeliness of the data varies; many states keep their road inventory databases current (or almost current) for state roads. Local road databases, if available, can range from current to more than 20 years old. Many states are on a 5-year cycle to ensure that all roads are inventoried and the data are accurate. Historical data for most of the states replying were available only on archives and most archive annually.

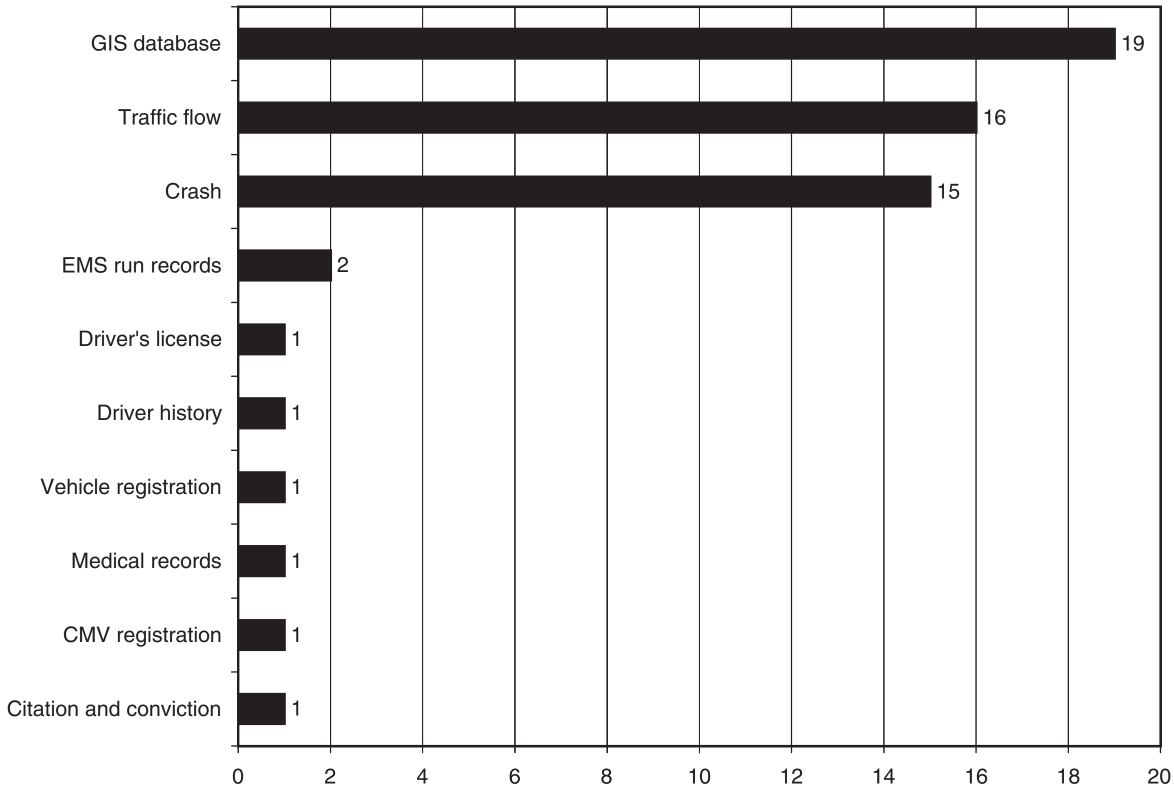


FIGURE 7 Reported linkages from road inventory database survey (20 respondents).

Linkage to crash, traffic, and GIS was possible in all but a few of the states. Figure 7 provides a distribution of the reported linkages to multiple sources. Florida stated that database linkage was possible to a great number of state agency databases outside of the DOT. GIS usage with complete integration of roadway inventory and traffic data was reported by 9 states and limited integration for specific applications was reported in 10 others. Other linkages with bridge, work zone, maintenance, project management, financial, and pavement monitoring systems were also reported by a small number of states.

Management of road inventory data is accomplished through varying types of linear reference systems. The two primary linear reference systems used by state DOTs are route-milepost (75%) and node-to-node (25%). All states noted that they can link to GIS; however, few had complete GIS integration. Most of the GISs used by the state can link to either linear reference system method. Route-milepost data can be accessed using dynamic segmentation.

Road Inventory Database Survey Summary

As noted in the crash database survey summary, route-milepost is the most common linear referencing system in use by state DOTs. Unfortunately, the route-milepost system does not easily allow for multiple years of historical road inventory data to be readily available for analysis. This makes linkage to historical crash records difficult. Roadway inventory databases are dynamic and constantly changing. Using the route-milepost system, there is no good way to manage change dates for specific pieces of information (e.g., the date that raised pavement markers were added to a section of roadway or the date when a traffic signal was added to an intersection). With hundreds of data fields for each record, managing change dates is a challenge. Most states archive the road inventory database each year, but not all roads are updated annually. Therefore, it is difficult to establish a link between road characteristic changes and safety improvements without chasing a significant paper trail of contract documents.

Federal mandated data programs such as those for bridge structures, railroad crossings, and HPMS have a strong effect on states' comprehensive collection of data. For bridge and pavement data elements, all states reported collecting these data elements comprehensively, whereas for elements such as road geometric elements (horizontal and vertical curvature), less than half of the responding states mentioned collecting the data elements comprehensively—most collect samples or on an as-needed basis if at all. Overall, a number of data elements required by safety programs (i.e., cross-slope, barriers, and intersection elements) are also underreported.

According to the survey, technologies were used sparingly except for pavement management/video-log. Where federal programs require more comprehensive data, states have adopted technologies to increase their efficiency with these data collection activities. However, many of the data elements are still collected manually with pen and paper or pulled from plan and profile sheets. Expansion of this type of data collection system would be cost prohibitive. Additionally, much of the data collected in hard-copy format must be entered or scanned, requiring additional labor costs.

Availability of AASHTOWare products for data management for federal requirements is seen as a benefit to the states. These software packages are typically designed to be flexible for use in most states, while allowing nationwide analysis of exported data. Further development of the anticipated TSIMS, while daunting, is expected to be an important venture.

TRAFFIC OPERATIONS DATABASE SURVEY RESPONSES

Technologies used for traffic data acquisition, processing, storage, and maintenance requirements vary by their intended applications. Although the survey was intended to query states regarding specific traffic operations databases, most states reported on the use of technologies for traffic operations data collection in general or with respect to the pavement monitoring system or advanced traffic management systems. Many of the problems in reporting arise because most states do not have one centralized database for collection of traffic operations data. Given these disparities in reporting, the following survey summary provides examples of acquisition technologies as related to specific applications. General trends are provided when applicable.

Survey responses were received from 16 state DOTs: Colorado, Connecticut, Florida, Georgia, Hawaii, Illinois, Iowa, Massachusetts, Minnesota, Missouri, Oregon, South Dakota, Tennessee, Texas, Washington, and Wisconsin. Figure 8 shows the geographical distribution of states responding to the traffic operations survey.

Acquisition

Traditionally for planning, design, and evaluation different data acquisition tools have been applied for various data types. Only a few survey respondents identified any specific types of data collection technologies. Missouri reported satisfaction with nonintrusive sensors for collecting traffic data. Examples of technology-oriented data acquisition tools, compiled from reviews of literature and survey responses, are provided here.

FIGURE 8 Geographical distribution of states responding to the traffic operations database survey.

TABLE 2
PERMANENT TRAFFIC MONITORING TECHNOLOGY USE: TECHNOLOGY DATA

Technology	Speed	Volume	Occupancy
Manual Count Boards		1	
Road Tubes, Pneumatic Counter	1	1	1
Loop Detectors	12	12	7
Video Detectors	2	3	
Radar Detectors	4	5	
Laser Lidar Detectors			
Acoustic Detectors		1	1
Magnetic Detectors		1	1
Microwave Detectors	1	1	
Ultrasonic Detectors			
Active/Passive Infrared Sensors			
Automatic Vehicle Identification			
Vehicle Probes			

Electronic count boards (with computer interfacing capability) for counting intersection turning volumes have been used extensively. Additionally, the following automated detection systems can provide both count and presence data: inductive loops, magnetic detectors (two types: two-axis fluxgate and inductive coil), microwave radar, active and passive infrared sensors, ultrasonic sensors, acoustic sensors, and video image processors. In the existing systems, magnetic detectors, passive infrared, and ultrasonic sensors are not able to generate classification data. When asked which of these technologies are currently being used by the states, only a few states indicated using technologies beyond count boards, road tubes, loop detectors, and video detectors. Tables 2 and 3 provide detailed usage summaries for each technology as related to the collection of speed, volume, and occupancy traffic data elements in both permanent and mobile applications. A few states indicated participating in a pooled-fund study on Portable Non-Intrusive Traffic Detection Systems.

TABLE 3
MOBILE TRAFFIC MONITORING TECHNOLOGY USE

Technology	Speed	Volume	Occupancy
Manual Count Boards		8	4
Road Tubes, Pneumatic Counter	8	12	7
Video Detectors			
Radar Detectors	1	2	1
Laser Lidar Detectors			
Acoustic Detectors			
Magnetic Detectors	1	1	1
Microwave Detectors	1	1	
Ultrasonic Detectors			
Active/Passive Infrared Sensors			
Automatic Vehicle Identification			
Vehicle Probes			

TABLE 4
TRAFFIC CHARACTERISTICS DATA AND COLLECTION SAMPLE

Traffic Data	Collect Comprehensively	Sample	As-Needed
Speed	2	6	5
Volume	10	4	2
Vehicle Classification	6	8	2
Vehicle Weight	4	6	2
Axle Load	1	6	
Axle Spacing	1	7	1
Occupancy or Density		1	1
Origin and Destination	1	1	2
Air Quality	0	1	0
Pedestrian Counts			
Traffic Control	2		

Handheld radar meters have been used extensively to conduct speed studies. Automated detection technologies include inductive loop detectors, magnetic detectors (two types: two-axis fluxgate and inductive coil), microwave radar, active and passive infrared sensors, ultrasonic sensors, acoustic sensors, and video image processors.

Of the traffic operations data elements surveyed, the most comprehensively collected element is traffic volume. This makes sense because it is required for HPMS reporting. The next most frequently collected element was vehicle classification, followed by speed and vehicle weight. Table 4 identifies several traffic operations data elements and summarizes states' responses to whether the data are collected comprehensively, sampled, or collected only on an as-needed basis.

For travel time and delay studies, automated means of data collection includes test cars equipped with distance measuring instruments that are connected to a laptop or handheld computer. Automated detector systems used for speed and presence data acquisition can also be applied for collecting travel time data.

Processing

Software is the primary means of processing the raw data collected in the field. Two types of processing may take place: processing of sensor data to convert into traffic flow measure (e.g., the use of presence data at two sensors of known distance to compute speed) and processing of traffic flow measures to identify parameters important for control or other management functions (e.g., processing of speed and volume data to identify whether an incident has taken place).

Vendors that are supplying the automated detectors usually supply the software required for processing the raw data to convert into required traffic flow measures. Processing of the traffic flow measures to generate decision support input is done through an algorithm developed by an agency or through off-the-shelf software purchased by an agency. In addition, a major area of transportation research has been in developing these decision support algorithms using deterministic-, stochastic-, and artificial intelligence-based models. Several simulation models, including DYNASMART, DYNAMIT, INTEGRATION, VISSIM, and PARAMICS, have been developed to support real-time decision making by processing the traffic flow measures acquired by the sensors.

According to the survey responses, several states use software, either off-the-shelf or developed in-house, to process data collected by the sensors. Iowa uses software developed in-house to process manually collected turning movements. Missouri and Wisconsin use off-the-shelf software, TRADAS, for automated processing of raw data, performing quality checks, summarizing the data, preparing reports, and managing the data. Florida uses polling software, developed by a consultant, to continuously manage traffic monitoring sites. Florida reported that they have provided this software to the South Carolina DOT. Florida made enhancement to a survey processing software, originally developed in-house, to process short-term (seasonal, portable, noncontinuous coverage) traffic counts and vehicle classification surveys. Their software can read from a number of traffic counters (Peek, Diamond, PAT, Mitron, Numetrics, and ITS) and transform data to a common format for processing. The number one complaint identified in the state surveys was related to proprietary processing software.

Storage and Maintenance

As mentioned earlier, Missouri and Wisconsin use TRADAS software to manage their traffic data. The efforts are on-going in the real-time traffic operations, such as those included in intelligent transportation systems (ITS) applications for archiving the data collected to support real-time decision making and reporting.

Traffic Operations Database Survey Summary

Given the difficulties that the states had in responding to this survey, it is clear that additional efforts to define a more comprehensive system for traffic operations data collection and maintenance are needed. Several states indicated that multiple databases were maintained to house traffic operations data—some for ITS data archives, some for traffic signal data, and others to support volume requirements for HPMS. One of the overarching requirements of both IHSDM and SafetyAnalyst is the need for volume data. More integrated and effective data systems will be needed to meet these demands.

Although several states mentioned plans for deployment of portable nonintrusive traffic detection systems in the near future (5–10 years), few states have been early adopters. The use of portable nonintrusive technologies will be required to expand the traffic data needs of future safety analysis programs.

CHAPTER FOUR

OVERVIEW OF TECHNOLOGIES AND SUCCESSFUL PRACTICES

Through information obtained from the state surveys, extensive literature searches, general subject knowledge, interviews, and topic panel suggestions, a number of available technologies were identified to assist with safety-related data acquisition, processing, and storage and maintenance. Table 5 cites all technologies included in this synthesis. It shows technologies separated by data category (crash, road inventory, and traffic operation) and data function (collection, processing, and management). There may be some overlap in the discussion of technologies—particularly with respect to crash reporting, where several technologies may be combined into one electronic reporting system. In addition, in the processing and management data functions many of the technologies apply to all or most of the three data categories [denoted by an asterisk (*)]—when this occurs, the technology is generally covered in only one section.

The technologies are covered in order of data function (i.e., crash data collection > road inventory data collection > traffic operations data collection >> crash data processing, etc.). This chapter includes information on successful practices and evaluation outcomes in the use of various technologies. Specific attention is given to the efficiencies or benefits afforded by each of the technologies. State case studies are provided to showcase the uses of the technologies as well as define the benefits of the technologies.

CRASH DATA COLLECTION TECHNOLOGIES

Electronic Crash Reporting

The most important component of any safety data system is an accurate accounting of crashes that are occurring on the roadway network. Historically, crash records have been obtained through paper-based police reports collected at the crash site. The hard-copy reports are then submitted to a central location for entry into a crash database. Subsequently, issues resulting from illegible handwriting on the reports, key-entry errors during data entry, and inefficient data maintenance methods undermined the usability of the crash data.

With the advent of mobile computing, some agencies began developing electronic versions of the crash report. Although this helped solve illegible handwriting issues, the reports were still printed to hard copy format and submitted to a central database for duplicate data entry. The proliferation of wireless communications has ultimately led to the design of more efficient systems allowing immediate transfer of crash reports to a central location, with connection to central databases in the field for automatic completion of driver's license and vehicle registration information. Several such electronic crash reporting systems exist today including Iowa's TraCS, Nevada's Crossroads Traffic Collision Database, and Illinois Mobile Capture and Reporting (MCR) system. The following summaries of these systems will identify system components and, where available, implementation outcomes.

Traffic and Criminal Software

TraCS is used by both state and local law enforcement and motor vehicle agencies for improved crash report data collection. The TraCS application suite was developed through cooperation from consortium partners including the Motor Vehicle Division of the Iowa DOT, Iowa Department of Public Safety/Iowa State Patrol, FHWA Iowa Division, and sheriffs and police departments across the state. The objective of this partnership was to create a fully integrated safety management system by expanding on the state of Iowa's nationally recognized leadership in safety data collection. This approach served as a model for all states to draw upon in their efforts to improve their data collection and safety management system processes. The software consists of a variety of customizable modules that can be combined to meet the needs of various state agencies through the software developer's kit. The software is licensed free of charge and thus is being considered for implementation in a number of states. To date, Iowa, New York, and Delaware have the most comprehensive implementations (*17*).

The software contains two application components—TraCS Mobile and TraCS Office. TraCS Mobile software is used to collect field data (crash reports and citations) and can be customized to resemble paper reports. TraCS Mobile works with mobile laptop computers, bar code scanners, mobile printers, host workstations, and statewide data communications. The application software also has a GIS Incident Location Tool, supports barcode and magnetic strip reading, stores electronic signatures, and provides electronic diagramming options. The TraCS form allows any type of

TABLE 5
TECHNOLOGIES BY DATA CATEGORY AND DATA FUNCTION

Data Category/Function	Collection	Processing	Management
Crash	Electronic crash reporting Portable GPS receiver Barcode reader Magnetic strip reader Digital video/photo Event data recorder Laser measurement	Document scanning* Wireless communications GIS*	AASHTOWare—TSIMS Middleware* Network applications*
Roadway Inventory	Electronic inventory logs Highway measurement vehicles Video-log AASHTOWare—Trns* port Satellite imagery	CAD exports Document scanning* GIS* Automation software	AASHTOWare Middleware* Network applications*
Traffic Operations	Digital video Nonintrusive traffic counters ITS systems	GIS* TRADAS	ITS data archives Middleware* Network applications*

*, Technologies that apply to all or two of the three data categories.
CAD = computer-aided design; TRADAS = Traffic Data System.

file to be stored with it, including images or video from a digital camera or images from a flatbed scanner. The in-vehicle mobile data terminal (see Figure 9) can download data and image files to a desktop computer or agency network. TraCS Mobile allows users to collect, validate, and print information immediately and later transfer the data to the TraCS Office. After the data has been stored in TraCS Office, it can be transmitted to the state repository (*17*).

There are four different types of diagramming options available in the TraCS software. One captures hand-drawn images, whereas another makes use of templates for drag-and-drop diagramming. With the purchase of an additional software license, Visio 2000/2002 and Easy Street Draw can be used within TraCS.

TraCS Office is the agency-level database repository that can be used to analyze data collected from TraCS Mobile. It includes all of the functions found in TraCS Mobile and an export function is available to archive data. TraCS Office can use Access 2000, Oracle 9i, or SQL Server 2000 for form data storage.

FIGURE 9 TraCS in-vehicle mobile data terminal (*17*).

Iowa's TraCS implementation includes some components that are used statewide:

- Crash reporting,
- Citation issuance,
- Incident reporting,
- Motor carrier inspection reporting, and
- Operating while intoxicated reporting.

When the crash reports reach the DOT, they are automatically stored in the DB2 database. Additionally, the reports are stored in an Oracle database upon reaching the Iowa Court Information System. Other agencies receive various relevant reports such as the Commercial Motor Vehicle Safety Inspections report and the National Incident Based Reporting System report.

FHWA (*18*) sponsored a study to determine the benefits of using computerized crash report forms versus paper-based forms. The FHWA study found that the number of missing and erroneous data elements was reduced with the use of computers. Figure 10 shows a comparison of errors found between computer and paper-based forms. In part, this is because the Iowa TraCS form has an automated process for checking the accuracy and completeness of the computerized form. The study team found that the reduction in errors did not come solely from the computer catching errors, but rather by giving officers feedback concerning the errors, whereupon the accuracy and completeness of their reports quickly improved.

In the first five years after implementation, the Iowa TraCS project has resulted in some marked improvements (*19*):

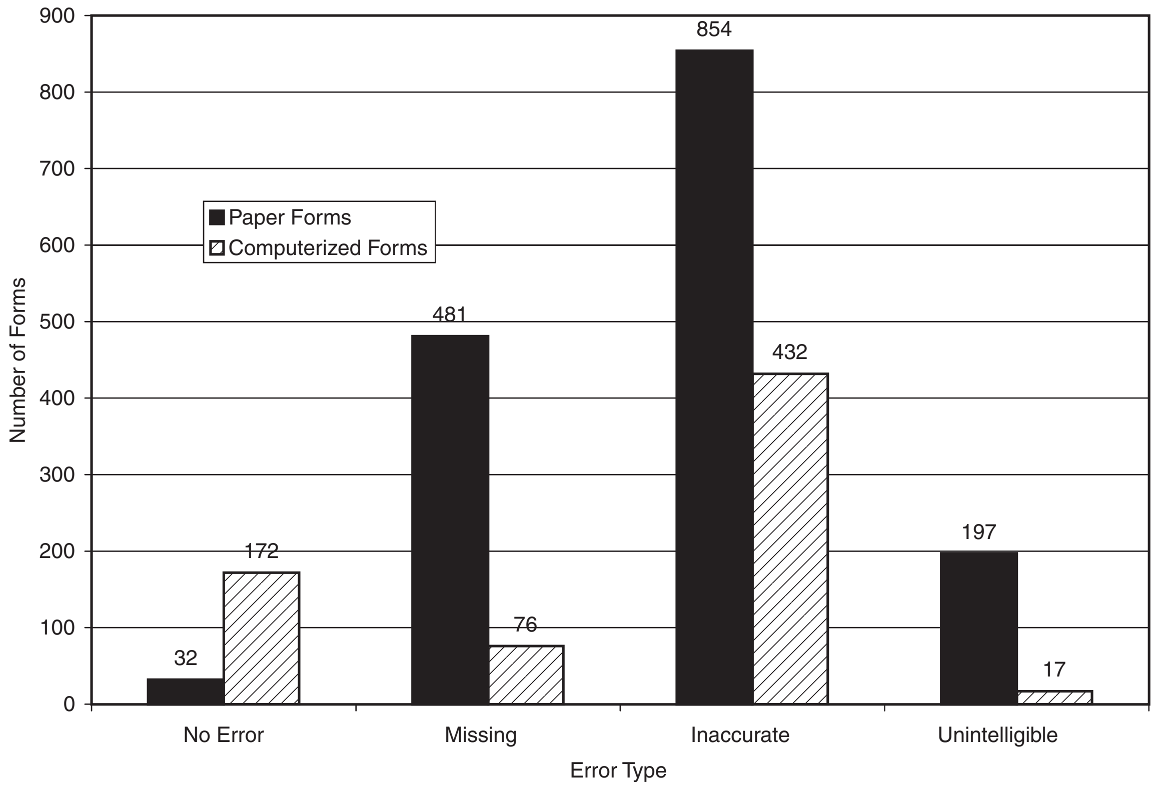


FIGURE 10 Analysis of errors related to data entry method (*18*).

- Reduction in the amount of time that incident information is electronically available to the state to as little as one day,
- Elimination of duplicate data entry by law enforcement agency staff,
- Significant reduction of errors on accident reports, and
- Reduction in time spent completing accident reports.

The data have been used to make informed decisions, and to identify and address emerging safety trends such as aggressive driving. Specifically, archived data have been used to:

- Conduct before-and-after analyses to determine the safety improvement of construction projects;
- Conduct analysis of railroad crossing crash data to determine if changes in traffic controls are necessary;
- Determine the effectiveness and adequacy of traffic controls at intersections;
- Develop and prioritize pavement resurfacing projects for safety enhancement; and
- Evaluate the safety effectiveness and performance of traffic control signing, channelization, and marking at work zones, and make appropriate changes immediately after problems arise.

As mentioned in the state survey, Delaware used the software developers' kit to modify the TraCS software, and they have been using it statewide for several years. An evaluation is in progress. Delaware was a runner-up for the Association of Transportation Safety Information Professionals Best Practices Award in 2004. In the application (*20*), Michael McDonald, Director of Information Technology for Delaware State Police, stated that

> The benefits of this project in time savings alone are priceless. Officers who used to hand write traffic reports, including summonses, tow slips, and insurance information exchange sheets spent their time over and over again recording the same information on the various forms we used. If an operator was being arrested for more than two charges, the same information on the traffic summons needed to be replicated on another one. Time savings have been preliminarily measured to be approximately 2 h of an officer's day. This translates into more unobligated patrol time; time that is directed by supervision to troubled areas experiencing high rates of crashes or moving violations. This risk management approach by our supervisors in directing patrols, which resulted from time savings, is directly related to the feedback we are able to provide them to stay abreast of life threatening highway, roadway, and vehicle variables affecting our crash experience.

The New York TraCS program was selected as the winner of the 2005 Association of Transportation Safety Information Professionals Best Practices Award. In studies completed in New York since the implementation of TraCS, the New York State Police has found (*21*):

- The length of time a motorist is stopped along a highway to be issued a ticket has decreased by nearly 50%.
- The police agencies now have a database of all ticket and accident data that is updated daily without requiring

reentry of the data. This allows officers to increase patrol time and spend less time in the station.

- The error rate for tickets at the department of motor vehicles has dropped from 17% to under 3%. This has resulted in a reduction in data discrepancies, including incorrect and missing information. Legibility errors resulting from poor handwriting on tickets and crash reports has been eliminated.
- Large truck and bus crash reports that meet federal filing requirements have gone from a 23% submittal rate before TraCS, to a 100% submittal rate when the report is completed with the TraCS program.

TraCS is currently licensed by 18 states and 2 Canadian provinces (see Figure 11). Other states and territories are developing their own system or already have a system that would not easily incorporate TraCS. Although many states are still in the evaluation stages of using TraCS, some states have already seen benefits from using the software. The states that use TraCS have created a user group to share information and resolve problems. TraCS users in Georgia have seen significant savings owing to reduced paper work and data entry. Some states are developing their own modules to use within the TraCS system, and these will be evaluated as they are implemented (*17*).

Crossroads Software

This software includes a Traffic Collision Database and a Handheld Citation and Report Writing Program. Nevada developed their software through Crossroads Software, Inc., working with people in-house. According to the state questionnaire, Nevada has been using the software statewide for less than two years and has found that it is cost-effective and improves efficiencies in data collection. Nevada encountered implementation issues in that the various law enforcement agencies have differing records management systems and needs. "Interfaces for the agencies to send data to the statewide repository and to the courts had to be developed separately. Training was also a huge undertaking as each agency had differing processes and procedures for data collection."

The Traffic Collision Database works in a Windows environment with standard or customized forms. It is capable of data input, data analysis, reports, and queries for traffic collisions, citations, and instances of driving under the influence (DUIs). GIS mapping, collision diagrams, printing, street name verification, and import/export functions are other features of this software. The Queries and Reports section is the most substantial portion of the database. Various parameters can be sorted by street name, primary

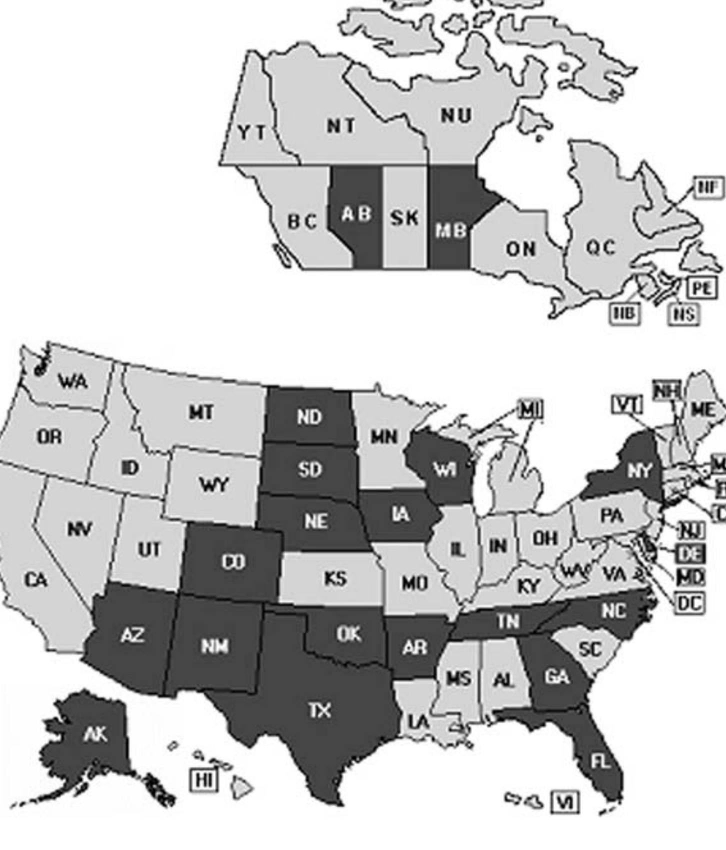


FIGURE 11 States and provinces that have licensed TraCS software (*17*).

collision factor, number of injured, and other. Multiple types of prepared reports are available for printing. GIS maps are possible through the included ESRI ArcView software. The Traffic Collision Database is being used in local and state agencies, including those in Arizona, California, Nevada, New Jersey, and Washington State (*22*).

The Handheld Citation and Report Writing Program offers law enforcement a software suite to write citations, DUIs, and traffic collision reports. The handheld device operates within a Windows Pocket PC environment to facilitate the writing, printing, reporting, and analyzing of citations. The program allows for information such as the location, vehicle, personal information, and officer notes to be included. It is capable of capturing signatures and fingerprints, reading driver's licenses by means of a magnetic strip or license bar code, and printing citations on a portable printer. The handheld device links with a desktop or laptop computer to download the information into other systems or databases, such as the Crossroads Software Traffic Collision Database, for records management, analysis, or transmittal (*23*).

Mobile Capture and Reporting System

The MCR is an example of a state-developed traffic crash reporting system. In 2004, Illinois was a runner-up for Best Practice Recognition from the Association of Transportation Safety Information Professionals for the MCR. The Illinois DOT, Illinois State Police, and local law enforcement worked together to develop an electronic system used for crash records capture and submittal. The actual cost of this project was $1,494,328. Scheduled completion of the implementation of the MCR project was set to have all 1,100 Illinois State Police troopers statewide using MCR by June 2005, as well as county and municipal law enforcement agencies (*24*).

The MCR project, which is part of the Illinois Crash Reporting System, provides electronic crash reports, citations, overweights, and warnings with additional reports added to the project as necessary. By integrating MCR with the Illinois Law Enforcement Agencies Data System, officers can import driver and vehicle information into the crash report. A crash diagramming tool is available with drag and drop functions to create the scene of the crash. Crashes can be located graphically through GIS capabilities in the office. If in the field, GPS can be added to the system to allow the officer access to the exact position of his or her vehicle. Another capability of MCR is driver's license barcode scanning, which automatically inputs license data into the correct forms. Additionally, if the police officer enters the zip code, the city, state, and country are provided automatically (*24*).

Additional system innovations include integration with VINAssist to determine vehicle information from the VIN and with the Federal Carrier Database for automatic data input of commercial carriers based on the U.S.DOT number. The reports include the ability to set default values that can be overwritten, error messages when problems arise, officer notes, attachment sending, transfer capabilities, and spell check. A crash report can be printed at the scene or at the office.

The MCR project was dependent on teamwork involving different agencies, and the success of the project is attributed to initial and continual involvement in every phase of the project by law enforcement. An evaluation of the program determined that law enforcement officers found MCR to be user-friendly, and the amount of time they spent reporting traffic crashes decreased. Processing costs for the Illinois DOT dropped three dollars per crash report, and electronic crash reports are received in hours instead of the 45-day average for paper reports. As stated in the application, "MCR benefits the [Illinois] DOT Division of Traffic Safety and Illinois law enforcement through improved public safety and efficient use of available funds and personnel. Responsiveness to the public has increased, and the ability to meet state and federal requirements has improved" (*24*).

In summary, the various electronic crash-reporting tools have shown benefits in the timeliness, accuracy, completeness, efficiency, and integration of crash reporting. The tools include a wide range of capability and level of integration with other tools and data sources. Some of the noted benefits included time savings by officers in the field, reduction in time of reporting to a central location, elimination of redundant data entry and errors owing to illegible handwriting, and more accurate and complete data from automated error checking.

Portable Global Positioning System Receiver

The Illinois MCR included crash location based on the availability of in-vehicle GPS systems in police vehicles. Such systems are usually connected to in-vehicle computing terminals to allow for the capture and recording of GPS coordinates automatically by software programs. Another option for capturing crash location is through a handheld GPS receiver. These receivers are small (see Figure 12), relatively inexpensive (approximately $100–$150), and have accuracy in the range of 3–5 m. The portable GPS units can be used to determine position latitude and longitude and then record the position information on the paper report form.

Late in 2003, the South Carolina DOT (SCDOT) purchased handheld GPS receivers for the majority of the police officers responsible for collecting crash reports. In 2004, approximately 90% of the reported crashes included latitude and longitude crash coordinates. Although this provides a substantial time saving over manually locating crashes post hoc, there are still some issues to be resolved. An ongoing evaluation of the data (*25*) finds that officers have used multiple coordinate designations (decimal degrees, degrees-minutes-seconds, and

FIGURE 12 Handheld GPS receiver (*Source*: Garmin.com).

state plane) to log crash locations. In some cases, the latitude and longitude fields are reversed and, further, the number of decimals is sometimes truncated. The problems identified are not insurmountable and can be resolved with additional training and practice with using GPS devices by police officers.

Green and Agent (*26*) also evaluated the accuracy of using GPS for locating crashes. The analysis showed that the GPS unit is capable of obtaining accurate position data at the crash site to allow proper location identification for crash analysis. The researchers studied a random sample of 100 crashes—comparing the accuracy of the GPS position version with the accuracy of a route-milepoint position. Of the 100 crashes, 55% were found to have an accurate GPS reading and 58% were found to have an accurate route-milepoint location. The authors also noted that there was a large variance between the two methods by county and police agency. The largest source of errors for GPS was related to operator error rather than equipment or environmental issues. Suggestions for improvement of GPS accuracy included additional training, proper use of GPS unit, care when recording GPS coordinates on the crash report, and minor modifications to the crash report. The errors in route-milepoint locations primarily dealt with improper interpretation of the milepoint log, inaccurate use of the available mileposts, and the lack of knowledge regarding currently available data.

A previous evaluation of emerging technologies for traffic crash reporting showed similar results for GPS crash location data collection (*27*). The GPS was found to work best in conjunction with a GIS and mapping on the in-vehicle computer terminal. The automatic generation of a map based on the GPS coordinates allowed officers to verify or modify the position of the crash, thus leading to more accurate crash location information.

In summary, handheld GPS devices can provide highly usable position information, but should not be used as the only source of location information. GPS latitude and longitude do not provide a meaningful description of the crash position in the absence of a GIS system. Because GPS is subject to errors from signal blockage, start-up errors, and multipath errors, the position may not always fall within a reasonable distance of the actual crash location, and the reporting officer may not be aware of this error. Therefore, until integrated computer-aided reporting allows for verification of the position on a map, officers should continue to obtain traditional route, intersection, and distance information as a back-up. The benefit of using handheld receivers is attained in reduction of manual coding of crash locations in a route-milepost or linear referencing system.

Research undertaken by the North Carolina Highway Safety Research Center (*28*) used portable GPS receivers in a different way to obtain positive safety benefits. With a top-ten ranking in U.S. fatal truck-involved crashes, the North Carolina State Highway Patrol began experimenting with the use of GPS both for tracking and event capture to document enforcement activities. Inexpensive portable GPS receivers were integrated with in-vehicle computers in 50 motor carrier enforcement vehicles in the 12-county area surrounding Raleigh–Durham. The in-vehicle installation is shown in Figure 13. Continuous tracking of x, y location at 3-s intervals provided information regarding the location and time of regular operations. Enforcement events were captured using a software program on the mobile computer, which was connected to the GPS receiver. After geocoding all truck-involved fatal crash events, GIS analysis indicated the presence of areas experiencing higher percentages of truck-involved crashes and lower percentages of commercial motor vehicle enforcement. These discrepancies were used by motor carrier enforcement to reevaluate the spatial distribution of enforcement personnel. The North Carolina State Highway Patrol has a longer-term goal to apply these techniques to all vehicle crashes and enforcement activities.

Barcode, Magnetic Strip, and Radio Frequency Identification

Data linkage is typically affected by two elements:

1. The availability of the data element and
2. The accuracy of the data element.

Based on research by Miller (*29*), the average person's memory span is limited to 7 ± 2 characters. Therefore, somewhere

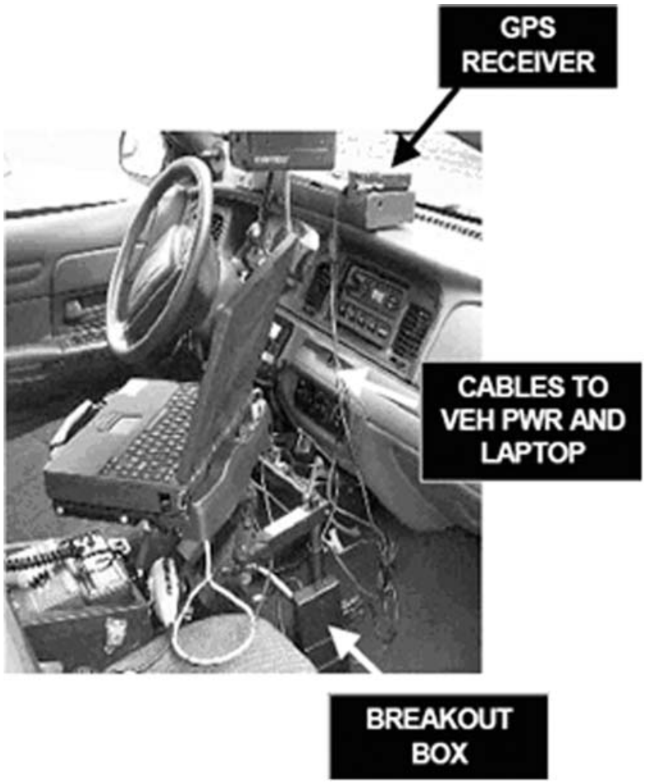


FIGURE 13 North Carolina State Highway Patrol Motor Carrier Enforcement Activity Monitoring Equipment (*28*).

FIGURE 14 Barcode scanner and magnetic strip reader (*17*).

between five and nine characters defines the maximum capacity of working memory when *full* attention is deployed. Given this finding, it is unrealistic to expect officers to collect lengthy data elements in the field without error. In most current state crash data systems, a large number if not all of the data elements are collected using pen and paper by police officers in the field at the site of the crash. In such a situation, the officer is balancing the crash investigation, crash reporting, emergency medical response, and traffic control simultaneously.

Many of the crash report elements are often used as linkages between databases such as driver's license number (approximately 9 characters), VIN (17 characters), and license plate (6+ characters). To account for this error potential, the CODES project developed a probabilistic linking algorithm that searches for similarities across multiple pieces of data to match cases among multiple data sets. Although the software will usually not allow 100% matches, its use greatly increases the number of matches. However, technologies for capturing driver's license, vehicle registration, and VINs have been available for some time. The technologies are the same as those used by grocery stores (barcodes and barcode scanners) and credit card companies (magnetic strip and reader) (see Figure 14).

The concept of a police officer gathering all the necessary information about the driver and his or her vehicle by simply scanning a barcode or swiping a magnetic strip is very attractive. The most obvious benefit of this technology is found in the accuracy and completeness of the gathered information. Other benefits include the efficiency and cost-effectiveness of a single card swipe, and storing the data permanently in the electronic accident record for each incident. Other information from the accident scene will still need to be recorded manually; however, much of the required information can be gathered in seconds using these technologies. The New York TraCS program has been using these technologies with success. Figure 15 shows a New York State Highway Patrol Officer using barcode scanning technology to record driver's license information. As mentioned previously in the discussion of benefits associated with the implementation of the TraCS program, the length of time a motorist is stopped along a highway to be issued a ticket has decreased by nearly 50%. Significantly decreasing the amount of time it takes an officer to write a traffic ticket or collect accident report information reduces the time officers and motorists spend parked along busy roads, thus reducing chances of accident, injury, or traffic disruption.

Smart Card technology ranges from magnetic strips on the back of the card to an embedded microchip. The magnetic

FIGURE 15 New York State Highway Patrol officer uses barcode scanning technology to record driver's license information.

strip card has clear advantages over the chip card, because it can be read by most existing card reader technologies found in restaurants, grocery stores, and automatic teller machines. Also, magnetic strips can be designed in such a way that not all card readers can access all the information that is contained on the card. In contrast, chip-based cards (see Figure 16) would require new card readers to be purchased nationwide—a costly requirement. There is also potential for the information held on the chip card to be scanned without the owner's knowledge (*30*). Radio Frequency Identification (RFID) allows chip-embedded cards to be scanned from a distance, along with providing tracking capabilities to the government, so that cards with RFID tags could be located along with their owners (*31*). The RFID tag would also be strategically placed beneath the photograph so that if the photograph were tampered with, the card would be deactivated and could no longer be used (*32*). Another advantage the magnetic strip card would have over the chip card is longevity. Magnetic strips can last up to 10 years, whereas chip technology has not yet been adequately tested and is not anticipated to last the normal 10-year renewal cycle (*33*). One major problem the magnetic strip card has is inadequate storage capacity. Some of the highest estimates so far for magnetic strip capacity are 1,800 bytes. Chip cards can store up to 4,000,000 bytes and are easier to update (*30*).

FIGURE 16 Embedded microchip technology (*34*).

Japan was expected to issue up to 80 million chip-based RFID-enabled driver's license cards in 2006. Information that will be contained on the cards is limited to the same information that is printed on the card along with a photograph and a digital signature. The National Police Agency will use the cards' capabilities to administer traffic tickets while recording accurate information about the driver and vehicle for accident records (*33*).

Florida is leading the way in high-technology driver's license security and information in the United States owing to the September 11, 2001 (9/11), hijackers obtaining Florida driver's licenses. Florida boasts of having one of the most secure technologies with a 17 "layers of security" driver's license. Florida's emphasis is primarily on proof of identity and not so much on driver and vehicle information (*34*).

The Real ID Act passed by Congress in May 2005 will require all states to update their existing driver's license cards by 2008, and it is estimated that it will cost states up to $750 million dollars to implement, which includes not only new card technology but also new card reader technology. Several states are hesitant to implement the requirements of the Real ID Act because the proposed standards are unclear, especially as technology is ever-changing and privacy issues are becoming major concerns to many citizens in this post-9/11 era (*35*). The Real ID Act's primary goal will be to ensure that the owner of the card is actually who they claim to be. Information contained on the card will not only be useful in proving identity but will also be useful to law enforcement in gathering driver information, such as name, address, social security number, date of birth, and the VIN in the event of a vehicular accident.

With the nationwide implementation of smart card technology, new ways of collecting driver and vehicle information will be available to law enforcement. Although other information will have to be acquired by other means as it relates to accident sketches and environmental analysis, the most important step of accurately and efficiently collecting important data that is often used to link all persons involved in traffic accidents will be as simple as swiping an individuals driver's license.

Laser Measurement and Digital Photography

In a crash investigation, the time immediately following the vehicle crash is crucial. Physical evidence of the crash may disappear or be altered when the site is cleared. Hence, data must be collected and recorded without delay. While collecting evidence, the crash investigator must keep in mind the information required for enforcing traffic laws, planning accident prevention, and preparing for court proceedings regarding accident cases.

Physical outcomes of the crash are recorded in the form of measurements, sketches, post-crash diagrams, and photographs of the accident scene. Conventionally, a measuring tape has been used as the primary data collection instrument; however, this is a lengthy method and the reconstructionist has to take separate elevation measurements. There is also a risk of transposing errors when making and entering records into an electronic format. Increasing traffic congestion, reduction in staff, and increases in workload emphasize the need for new crash site data collection techniques (*36*).

The requirements of an ideal crash site data collection system are portability, flexibility, ease of use, and the ability to collect a high number of measurement points. Although several different systems are in use by police agencies and DOTs, laser measurement systems and photogrammetry are the most popular technologies currently available (*36*).

Numerous coordinate measuring machines are used in combination with three-dimensional digitization. The "Total Station" (Figure 17) is a portable crash scene measurement and mapping tool that has high accuracy and reliability. However, it greatly inconveniences traffic because the roadway may be closed for hours during the mapping of the crash scene data points. Only 25% of crash reconstructionists use a total station. Total stations range in cost from $6,000 to $25,000, which can be unaffordable for smaller crash reconstruction firms. This, combined with the risk of a secondary accident, has raised the need for alternative technology (*37*).

Laser-based measurement systems are another mobile technology for crash scene measurement. These systems are faster and more accurate than hand measurements, yet less costly than total stations. Laser-based measurement systems involve less equipment, are more compact, and can be handled by a single officer in the field saving time and money. Because the equipment is affordable, more units can be purchased. The laser system is used only to measure and record data, special drawing software is required to create a diagram from the measurements.

FIGURE 17 Total station survey device.

Another laser-based measurement option is an angle encoder. The true slope is obtained by measuring angles with the inclinometer in the laser (angle encoder). The true slopes allow connection of drawing lines in three-dimensional (3D) diagramming packages. Sometimes, however, a total station is necessary. In larger crash scenes only a total station can track a prism out to points further than you can see with the angle encoder system (*38*).

Another up-and-coming portable method for mapping crash scenes is close range photogrammetry. Photogrammetry is based on the mathematical–geometrical law that the spatial location of a point is clearly definable if it is represented by at least two images. Two conditions must be satisfied to use photogrammetry techniques: (1) the two images must be taken from different directions, and (2) the location and orientation of the camera must be accurately known (*39*). A digital camera is used to acquire the necessary scene details and evidence. From the two-dimensional digital camera images captured from various angles at the scene, 3D measurements are obtained. A 3D model of the scene is created from the data points obtained using special software. The 3D model is then converted to a 3D diagram using a computer-aided design (CAD) drawing program. The software has built-in 3D symbols and libraries of drawing elements including cars, trucks, and people. One person can model a crash scene on their own using a digital camera and special software to create the 3D diagram (*40*).

There are many advantages of using portable laser measurement and photogrammetry technologies to map crash scenes. There is economy in time and money; one officer can conduct data collection and make detailed drawings without assistance. The collected data are accurate and it is possible to diagram the data at the scene. That data can be collected immediately after the crash maintains the validity of the evidence. Furthermore, the possibility for secondary crashes caused by delay and road closure is reduced by swift data collection.

Event Data Recorder

One of the most promising technologies for advancing highway safety research is the event data recorder (EDR). An EDR collects and stores critical vehicle and operator performance data for the seconds before and during the crash. NHTSA began using EDRs in the United States in the 1970s.

In 1974, NHTSA equipped 1,000 vehicles with disc recorders (*41*). These recorders collected changes in velocity and actual deceleration rates for 26 crashes where an instrumented vehicle was involved. Over the study period, the instrumented vehicles traveled a combined 26 million miles. The cost of the equipment and limited return in crash data delayed further EDR research for some 20 years.

In 1997, the NTSB issued a recommendation to NHTSA to pursue vehicle crash data collection using EDRs. The next year, the NHTSA Office of Research and Development formed a working group of industry, academia, and other government organizations to participate in a forum to study EDRs (*42*). The working group researched eight specific aspects of EDRs including status of EDR technology, data elements, data retrieval, data collection and storage, permanent record, privacy and legal issues, customers and users of EDR data, and EDR technology demonstrations. The working group considered both original equipment manufacturer EDRs as well as after-market EDRs. The original equipment manufacturer systems were originally developed to sense and record crash forces for restraint deployment. After-market systems are usually developed specifically for recording crash events for training and litigation purposes and are primarily deployed in fleets. The conclusion of the NHTSA working group was that EDRs have the potential to improve highway safety for all classes of vehicles, but that the degree of benefit is directly related to the number of vehicles with EDR and the ability of the current infrastructure to use and incorporate the data.

Current EDRs are capable of recording vehicle and occupant data for a few seconds before, during, and after a crash, such as precrash system status, restraint usage or deployment, and activation of an automatic collision notification system (*41*). Additional data that can be recorded and is required for new school buses and motor coaches include acceleration, speed, braking input, turn signal status, emergency status, and brake system status (*41*). NHTSA routinely adds EDR data to its crash databases to support its crash investigation program. Many newer model cars are equipped with an EDR. An EDR can measure the severity of crashes, vehicle speed, engine revolution rate, throttle position, safety belt usage, air bag readiness and performance, and brake application in vehicle crashes (*43*). These data are used to improve the safety and performance of the vehicles. The most important items for states are precrash speeds and determining safety belt use. It may be downloaded with the permission of the owner, at the request of law enforcement, or as required by law (*43*). EDR readers exist for several makes of automobile and cost between $2,500 and $3,000. The information may be used for crash reconstruction or for research with identification information removed (*43*).

A recent study by Rowan University (*44*) recommends a minimum set of EDR data elements for roadside safety analysis and procedures for the retrieval, storage, and use of EDR data from vehicle crashes to include legal and public acceptability of EDR use. The study concluded that:

- There should be a standardized method of retrieving data.
- NHTSA should require a crashworthy, universal EDR download connector.
- State and federal transportation agencies should use a common EDR database format.

The first standard for motor vehicle EDRs was created by IEEE, called IEEE 1616, in 2004 (*45*). The new standard IEEE 1616 "specifies minimal performance characteristics for on-board tamper- and crash-proof memory devices for all types and classes of highway and roadway vehicles" (*45*). The standard also covers device survivability and a data dictionary of 86 data elements. Before IEEE 1616, highway vehicles were the only major mode of transportation in the United States (including rail, air, marine, and pipeline transport) without an adequate EDR standard. Another vehicle EDR standard, IEEE 1616a, is under development and will require EDRs to store a history of time-stamped fault codes synchronized with other on-board motor vehicle devices.

The largest obstacle associated with the use of EDR data for highway safety research is related to privacy concerns. According to comments submitted by the Electronic Privacy Information Center in response to a proposed rulemaking released by NHTSA, "NHTSA must not mandate the use of black box technology without ensuring that strong privacy safeguards are in place to protect the interests of drivers" (*46*). The data recorded by EDRs might include the date, time, velocity, direction, number of occupants, airbag data, and seat belt use. Some EDRs could even collect location data and video, which are the leading components that raise privacy issues.

Setting privacy concerns aside, a great deal of information can be gleaned from EDRs. For years, safety analysts have had to rely on post-crash reconstruction to study events surrounding crash development. Now, technology exists to record specific data regarding the vehicle and operator performance before the crash. A thorough understanding of precrash conditions will allow engineers and safety analysts to proactively focus on critical precursor events rather than reactively focusing on post-crash analysis.

ROAD INVENTORY DATA COLLECTION TECHNOLOGIES

Electronic Road Inventory Logs

Roadway inventory data describe the physical features within a road's right-of-way. These data include geometric data, cross-sectional elements, traffic control devices, and pavement-related data. Various agencies at the local, state, and federal levels in the United States build and maintain large databases that provide inventories of positional and descriptive data for roadway elements and features. These inventories aid transportation planning, roadway maintenance, and performance monitoring. Most road inventories use distance along route (route-milepost) as the key reference for the data. Traditionally, vehicles equipped with distance measuring instruments measure the mileage of the roadway as it is traversed, whereas data collectors manually log pertinent features of the roadway. These "windshield surveys" typically involve logging data using pen and pencil and/or a digital device such as a notebook computer, palm pilot, or digital clipboard. Other manual methods of data collection include extracting data from construction and as-built plans and collecting data during field surveys.

Depending on the type of data, acquisition technologies include both manual methods and automated data collection. There are different levels of automation of data collection technologies. Although some attributes may be collected manually, the geographic location of the attribute might be captured in an automated fashion using an inertial navigation system or a differentially corrected GPS system. At a higher level of automation, data collection can be captured using sensors mounted to a vehicle that is operating at highway speeds (see the following section on highway measurement vehicles). These data would be directly passed to a digital database. Automated data collection must usually be post-processed in some fashion to check for accuracy and completeness, and to add additional attributes. The major benefit of automating data collection is the improved efficiency per lane-mile. The completeness and accuracy of the data are also increased.

Roadway Measurement Vehicles

The state of the art for collecting roadway data is through the use of a specialized instrumented vehicle. There are a number of companies that sell instrumented vehicles that collect various types of roadway inventory data. Most of these companies also offer contract services to collect data using their vehicles. All of the vendors have options for providing these vehicles with a full range of data collection capabilities. Depending on the options, the vehicle can collect geometry, cross-sectional elements, and pavement data.

Most commercially available instrumented vehicles are acquired by state DOTs for use in pavement monitoring systems. Pavement sensors (see Figure 18) allow for automated collection of roughness rutting, faulting, and texture data using noncontact sensors linked to a data acquisition computer system. Furthermore, some of these vehicle vendors provide a digital video processing capability that can collect lane width and other attributes in a semi-automated fashion.

An HSIS study was conducted in 1996 to determine the accuracy of the horizontal alignment data as collected by one of the commercially available pavement monitoring vehicles (*46*). This study, sponsored by FHWA, included road inventory and crash data from nine states for the purpose of performing safety analyses. Four rural two-lane roadway segments were selected, and data were collected using multiple passes on each segment. The study concentrated on the consistency of data, specifically if the results were repeatable from one pass to another, and if the data collected reflected accurately the data of the as-built design plans. The results showed that only 53% of the curve radii and 38% of the curve lengths met the established criteria for consistency. The conclusion of the study was that the data collection technology and post-processing software were not reliable in producing accurate horizontal alignments.

FIGURE 18 Road inventory vehicle with digital cameras and road profiling system (*46*).

In 1999, the Connecticut DOT developed an algorithm for processing the data collected from their instrumented vehicle (*46*). The algorithm used video-log data and the inertial measurement unit. The algorithm was part of a software package called the horizontal curve classification and display system. The results of the algorithm showed improvements in the consistency among multiple runs of the same roadway segment and accuracy with the as-built design plans.

In 2003, the Highway Safety Research Center at the University of North Carolina (UNC–HSRC) conducted a study to more fully evaluate the Connecticut DOT algorithm (*46*). The study included 10 rural two-lane roadway segments and 5 runs were made in each direction on each roadway segment using the Connecticut DOT instrumented vehicle. The results of the consistency analysis showed that 80% of the sites tested had an excellent or good level of agreement and all the points of curvature and points of tangency for a given site varied by less that 165 ft (50 m). The consistency analysis results indicated that there were problems producing consistent radii and lengths for horizontal curves. The results of the accuracy analysis showed that only 50% of the runs were considered to be in good or excellent agreement with the as-built roadway design plans (*46*).

In 2002, FHWA and Turner–Fairbank Highway Research Center began development of a digital highway measurement

FIGURE 19 FHWA–Turner–Fairbank Highway Research Center digital highway measurement vehicle.

TABLE 6
ACCURACY OF DIGITAL HIGHWAY MEASUREMENT VEHICLE SYSTEM COMPONENTS AND ANALYSIS

Parameter	Accuracy
Pavement Marking	Less than 1 in.
Edge of Pavement	Less than 6 in.
Vehicle Wander	Less than 1 in. when pavement markings are available
Cross-Slope	0.01%
Roadside Profile	0.03 in. at range of 7 ft 0.14 in. at range of 30 ft 0.24 in. at range of 50 ft
Horizontal Alignment	Less than 2 ft
Vertical Alignment	0.01%

vehicle (DHMV) (Figure 19) to measure accurately the horizontal and vertical alignments of roadways to generate road profiles. A multitude of sensors (e.g., lasers, inertial navigation systems, and differentially corrected GPS) provide data that are fused to define an accurate depiction of the road and roadside including horizontal and vertical curvature and roadside hardware. The DHMV is equipped with a high-accuracy, nationwide differential GPS system unit. In addition to this system, a high-resolution inertial navigation system, similar to the ones used in airplanes, is also used to determine heading, roll, and pitch data. The high-accuracy, nationwide differential GPS unit and the inertial system collect data on highway geometry as the vehicle travels at normal highway speeds. The 360-degree scanning laser mounted on top of the van in the rear constantly measures distances to road surfaces, roadside obstacles, and vertical obstacles. This device is also used to determine vehicle wander by accounting for the position of the vehicle in between the pavement markings or lane lines (see Figure 20). Accounting for vehicle wander in the lane greatly reduces the error of geometric position, especially within curve segments where drivers tend to naturally drift toward the inside of the curve. The resulting cross section shows the vehicle trajectory, centerline, edges of the pavement, edges of the lane markings, slope, guardrails, and other common safety hardware.

The DHMV uses post-processing software to extract the horizontal alignment curvature data measured from the centerline as defined by the points of curvature and tangency.

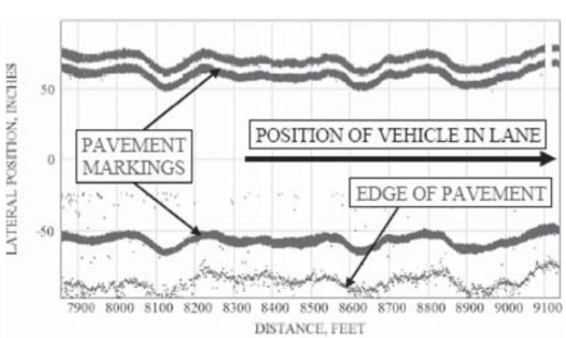


FIGURE 20 Lane wander measured by 360-degree scanning laser.

This software also computes the center, radii, and the degrees of curvature. A similar post-process is performed to determine the vertical alignment components, such as points of vertical curvature and tangency. The results of both analyses have shown improved accuracy over commercially available vehicles. Specific accuracy ranges for various cross-sectional elements are provided in Table 6. As a next step, FHWA and Turner–Fairbanks Highway Research Center plan to compare results from this inertial system with the GPS system to determine if a less expensive vehicle could be used with similar accuracy. The current cost of the DHMV is estimated at approximately $1 million.

The primary benefit of using specially equipped vehicles is a reduction in the amount of the manual labor required to survey roads or extract information from plan sheets to enable safety analysis. Using instrumented vehicles, data can be collected at highway speeds in a continuous fashion. In some cases there is a sacrifice in accuracy for collecting at highway speeds; however, this can be minimized with careful calibration of the vehicles.

Video-Log

A video-log is a video obtained from a specially equipped vehicle that provides a visual record of each highway as well as the immediate roadside environment. Most of the instrumented vehicles described previously contain a video-log function; however, video-logs may be obtained without all of the data elements provided by additional sensors typically found on the instrumented vehicles. Video-logs provide information about roadway and roadside elements without requiring site visits. The video-log usually contains images every 1/100th of a mile, which are stamped with information including date, highway number/name, and milepoint or GPS coordinate (see Figure 21). Video-logs are used to determine location of assets such as signs, signals, and roadside hardware. The videos may also be used to identify elements of interest such as driveways, intersections, and roadside hazards, or to determine roadside hazard ratings. Information may be retrieved as needed from the videos, or the videos may be processed systematically to acquire specific elements for a

FIGURE 21 Oregon state video-log frame taken July 28, 2004, on Pacific Highway East at milepoint −4.23.

roadway inventory file. Historically, the video-log process used VHS technology; however, more recently, state DOTs have turned to more advanced digital video systems. Digital video systems allow individual image frames to be recorded and referenced by roadway inventory logs or GIS systems.

State DOTs have varying schedules for maintaining video-logs. The schedules are usually driven by the number of state-maintained road miles and the need for updates as a result of construction activities. Most states are on a two to three-year collection cycle, and videos are usually retained for a minimum of two cycles. In the past, storage of the VHS tapes became an issue. Digital video retention is limited only by the amount of data storage provided by the computer network. Video is captured in both directions of the highway, and the view displayed is what the "driver" would typically see as they proceed along the road. Newer video systems are capturing multiple video feeds, providing a wider cross-section display of the roadway.

The Oregon DOT developed a digital video-log using Washington State's software as a base for the system. Two versions of the video-log are available for use—one for internal use and one for external/public use. The external use version can be found at http://www.oregon.gov/ODOT/TD/TDATA/gis/odotgis.shtml#Web_TransGIS_and_Video_Log. Several states, including California, Oregon, and Washington, have provided public access to video-logs for use by state visitors as well as other in-state users. In Oregon, approximately one-half of the state highway system is taped annually, with emphasis on Interstate and U.S. routes. The annual video-log seasons run from May 1 to April 30. The highway milepoint log report is a snapshot of data from the Integrated Transportation Information System database. A yearly snapshot is taken at the beginning of the taping season in May.

The Oregon video-log Internet application provides a good example of the capabilities of a digital video-log. The video-log is referenced to state highway numbers, although the Oregon DOT maintains a roadway reference log associating state highway numbers with Interstate numbers and other commonly used roadway names. The graphical user interface (GUI) shown in Figure 22 allows users to view entire routes with a pretimed video sequence or define specific locations along the route of choice for viewing. The GUI also allows users to rewind, skip forward or backward, pause, and extract or print digital images. The milepoint information stamped on each image provides a link to the road inventory log, which can be accessed directly from the GUI by pressing the Highway Log button beneath the image. The highway log provides route number, milepoint, roadway codes (roadway characteristic codes), and milepoint descriptions for each location where there is a change in roadway characteristic. A snapshot of a highway log is shown in Figure 23.

The California DOT (Caltrans) also maintains an Internet video-log application with access at http://video.dot.ca.gov/photolog. There are a couple of major differences between the two external applications. The Caltrans photo-log (Figure 24) provides a GIS map interface for identifying road sections for viewing, whereas the Oregon DOT interface is text-based. Furthermore, the Oregon DOT provides connectivity to view highway log information, whereas the Caltrans application does not. Regardless, each system provides both capabilities on internal systems.

Satellite Imagery

Remote sensing is the measurement or acquisition of information of an object by a recording device that is not in physical or intimate contact with the object. In practice, remote sensing is the use at a distance (as from aircraft, spacecraft, satellite, or ship), of any device for gathering information about the environment. Satellite and aerial photography images are the two most commonly used forms of remote sensing in transportation. Within a GIS, digital satellite images generated through remote sensing can be analyzed to produce a map-like layer of digital information about a transportation network and the surrounding land use. The quality of remote sensing data consists of its spatial resolution. Spatial resolution refers to the size of a pixel that is recorded in a raster image—typically, pixels may correspond to square areas ranging in side length from 1 to 1000 m. Remote-sensed data can be used in a similar manner to the video-log to identify elements of the transportation network. However, unlike the video-log, satellite imagery is typically georeferenced; therefore, elements are inherently tied to spatial coordinates.

In the development of recent crash prediction models (*3*, *4*), the number and type of driveways have been found to be significant factors. When access through driveways is not effectively managed, increases in crash rates, congestion, and

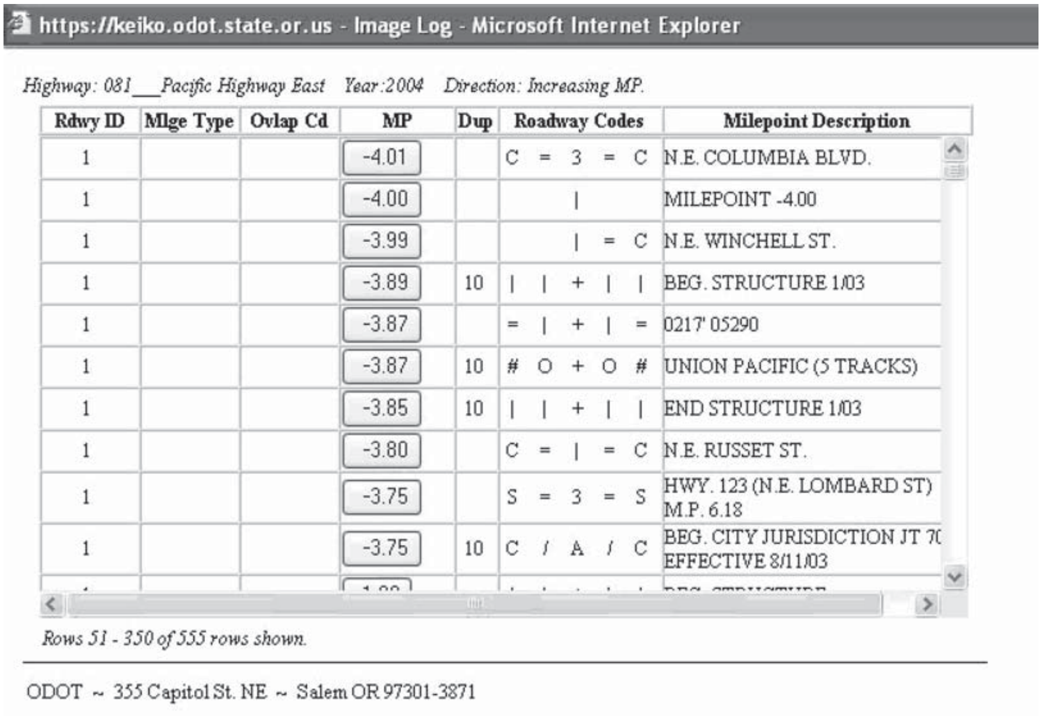
FIGURE 22 Oregon digital video-log graphical user interface.

motorist delay may result. Research has shown access management techniques to be highly effective in increasing highway safety and improving traffic operations—reducing crash rates on case study routes from 18% to 77% (*47*). Unfortunately, a number of barriers exist to prevent widespread adoption of access management treatments including:

- Resistance from the local business community,
- Lack of ability to predict future problem areas,
- Difficulty in applying models relating access control and safety *owing to cost and availability of data*, and
- Lack of a systematic approach.

Researchers from Iowa evaluated remote sensing as a method to reduce barriers resulting from the cost and availability of driveway access data (*48*). With the magnitude of roadway networks that most state DOTs are responsible for maintaining, the potential exists for remote sensing techniques to reduce the cost of data collection required for development of access management programs. Field data collection of roadway and roadside attributes is expensive, requiring vehicles, multiple personnel, and time to cover necessary mileage, regardless of the existence of subject characteristics. The researchers selected a 3.9-mile corridor in Ames, Iowa, for analysis. The corridor was subdivided into numerous segments of varying driveway density, median types, and land uses. Digital orthophotography was available for the corridor at 6-in., 2-ft, and 1-m resolutions. The corridor was measured in the field by researchers and the data derived from imagery was compared with the field observations. Table 7 shows that for the three levels of imagery, the 6-in. resolution provided reliable data for access attribute data collection.

Figure 25 shows the quality and potential uses of the 6-in. resolution imagery. Commercial and residential driveways, two-way left-turn lanes, and raised medians are all clearly visible in the images. It was noted that the time required to obtain the access data from images was 5 h, a clear reduction from the 10 h required to collect the same data in the field. Furthermore, remotely sensed, systematic data collection and processing, although less expensive than field data collection, was still considered time consuming, and thus expensive.



Rdwy ID	Mlge Type	Ovlap Cd	MP	Dup	Roadway Codes	Milepoint Description
1			-4.01		C = 3 = C	N.E. COLUMBIA BLVD.
1			-4.00		|	MILEPOINT -4.00
1			-3.99		| = C	N.E. WINCHELL ST.
1			-3.89	10	| | + | |	BEG. STRUCTURE 1/03
1			-3.87		= | + | =	0217' 05290
1			-3.87	10	# O + O #	UNION PACIFIC (5 TRACKS)
1			-3.85	10	| | + | |	END STRUCTURE 1/03
1			-3.80		C = | = C	N.E. RUSSET ST.
1			-3.75		S = 3 = S	HWY. 123 (N.E. LOMBARD ST) M.P. 6.18
1			-3.75	10	C / A / C	BEG. CITY JURISDICTION JT 7(EFFECTIVE 8/11/03

FIGURE 23 Snapshot of Oregon DOT highway log accessed from video-log application.

Trns*port

Several states have begun programs to convert paper-based plan and profile sheet archives to digital media. This effort is directed toward a more efficient plan retrieval process. Plan sheets are frequently needed to determine specific roadway characteristics for planning studies, safety studies, and rehabilitation activities. Unfortunately, in most states, only one copy of the as-built plan is maintained at either the district or state office; therefore, the usability is greatly diminished. By scanning the plans to PDF or another image file format, DOTs can provide access to all plans through intranet access. Access to plan sheets provides a wealth of information, but also requires a significant amount of manual labor to extract the information. Provision of original electronic drawing files in read-only format is a much more efficient means for retrieving data. An existing AASHTOWare product (*49*), Trns*port®, includes a module that allows for electronic plan files to be provided along with bid requests and other documents created during construction and maintenance contracting phases.

As with other AASHTO software, AASHTO Trns*port (*49*) was developed in the joint development process, whereby multiple states work together to develop a cost-effective solution while promoting best practices approaches. AASHTO Trns*port consists of the following 14 modules designed specifically for transportation agency preconstruction and construction management:

- CES®—Cost Estimation System
- PES®—Proposal and Estimates System
- LAS®—Letting and Award System
- CAS®—Construction Administration System
- BAMS/DSS®—DataWarehouse and Decision Support System
- Trns*port Expedite®—Electronic Bidding System
- Trns*port Intranet™—Web Browser Access to Trns*port Information
- Trns*port Estimator®—Cost Estimation Workstation
- Trns*port SiteManager®—Construction Management System
- Trns*port SitePad™—Handheld Data Collection Software for SiteManager
- Trns*port SiteXchange®—Subcontractor Data Transfer
- Trns*port FieldManager™—Construction Management Suite for Project Engineers and Inspectors
- Trns*port FieldNet™—Electronic Data Transfer System for FieldManager
- Trns*port TRACER™—TRAnsportation Cost EstimatoR.

Trns*port Expedite (*49*) is an electronic bidding system application designed to work with Trns*port PES (proposal and estimating) and LAS (letting and award), or any similar proposal preparation and bid letting management system. Expedite allows bidders to receive proposal information including item schedules, plan sheets, disadvantaged business enterprise requirements, and affidavits; enter all information

FIGURE 24 Caltrans photo-log graphical user interface.

TABLE 7
DETECTABILITY OF ACCESS RELATED ELEMENTS FOR VARYING ORTHOPHOTOGRAPHY RESOLUTIONS

Access Related Data Elements		Detectability 6-in.	2-ft	1-m
	Number	100%	>72%	>60%
Driveways	Land use	>99%[1]	>99%	*
	Presence	100%	>50%	**
Medians	Type	100%	>50%	**
TWLTL	Presence	100%	0%	**
	Type[2]	100%	0%	0%
Intersections	Frequency	100%	100%	100%

Source: Souleyrette et al. (*48*).
TWLTL = two-way left-turn lane.
[1]Based on number of driveways identified.
[2]Signalized or unsignalized.
*Not feasible on a case-by-case basis; in most cases evaluation can only be made based on the surrounding area under consideration.
** Segments considered for analysis did not have medians or two-way left turn lanes at the time the aerial photo was taken.

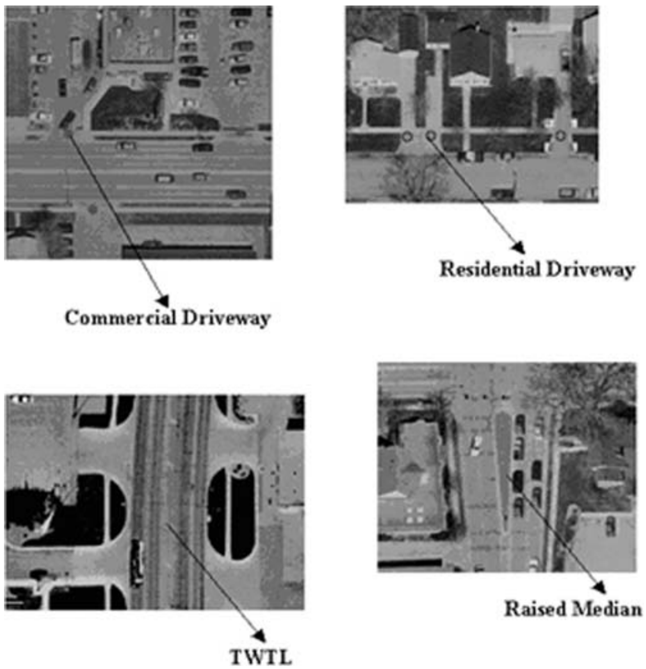


FIGURE 25 Quality and use of 6-in. imagery (*48*).

required for a valid proposal; and submit item bids in a secure machine-readable form.

Design plan and profile sections are typically created within a preconstruction group at the DOT and submitted to a contracting group for administration of the bidding and award process. The plans are used extensively in the bidding process and have historically been transferred to bidders in hard-copy format. With the change to electronic bidding processes, plan sheets are now being offered in electronic format to conform to the requirements of the Trns*port Expedite software. The Georgia DOT has implemented such a system (*50*). When design plans are sent to the printer, both paper and electronic versions are generated. The plans are posted on BidExpress as downloadable PDF files. DesignStore contains folders of plans listed by project number, divided into multiple folders including cover index, plan sheets, and revisions. These files are then maintained along with contract materials in accessible archives. The inclusion of actual CAD files would consume a significant amount of electronic storage capacity; however, by doing so, a significant amount of labor would be saved in the future. Common drawing export formats (XML) already exist and could be used to maintain drawing data in a long-term readable format.

In summary, using products such as Trns*port to maintain information about projects allows DOTs to construct historical timelines for roadways with minimal effort. Plan sheet archives provide an efficient method for providing access to design information and reduce labor requirements associated with site visits. Provision of electronic drawing files would only further reduce labor required to extract information from plans. The Georgia DOT has a novel interface that connects to the contracting archives. The Internet application will be discussed in a following section on data management—Middleware.

TRAFFIC OPERATIONS DATA COLLECTION TECHNOLOGIES

Nonintrusive Traffic Counters

Collecting traffic volumes allows agencies to determine expected crash rates for a road segment or intersection based on similar operational characteristics. This information can be used to rank roadways and intersections by priority for receiving safety funding. A sampling of traffic volumes is required for the HPMS; however, these are not comprehensive. The HPMS-sampled volumes provide a basis for determining federal monetary allocations to states under SAFETEA-LU.

Various devices are available for vehicle detection using both intrusive and nonintrusive methods. Nonintrusive technologies are those where deployment causes minimal disruption to normal traffic operations and installation can be done more safely than with conventional methods. Based on this definition, nonintrusive technologies are represented by devices that do not need to be installed in or on the pavement, but can be mounted overhead, to the side, or beneath the pavement by pushing the device in from the shoulder. Four common intrusive detectors that have been used for decades are inductive loop detectors, pneumatic road tubes, bending plates, and piezoelectric sensors. One downside of using any intrusive detector is the damage to the pavement during installation, maintenance, and replacement. Inductive loop detectors consist of a wire buried under the pavement. The wire creates a magnetic field that, when disturbed, recognizes a vehicle and counts it. Some disadvantages to using a loop detector include the susceptibility to installation errors, frequent inability to recognize motorcycles, and short life span. Pneumatic road tubes count vehicles by being placed across a lane and recording changes in pressure as vehicles pass over it. Tube counters can become dislodged and have limited lane coverage. A bending plate detects vehicles through weight and is typically used for weigh-in-motion. This costly metal plate is embedded in the roadway. An electronic (piezoelectric) sensor is placed in a groove cut into the road and measures the speed and possibly the weight of each vehicle. These sensors may last three or more years (*51*).

Although these intrusive detectors are quite common, the use of a nonintrusive detector eliminates the need to close lanes for sensor installation and replacement. Manual counts are one option for nonintrusive traffic volume data collection. They are easy to conduct; however, labor requirements are expensive, and the use of technology increases the accuracy of the counts. Other nonintrusive methods that are becoming more widespread include passive and active infrared; microwave and Doppler radar; and ultrasonic, passive acoustic, and video image detection. The Minnesota DOT and a consulting firm, with sponsorship from FHWA, recently completed a two-year test of nonintrusive technologies. The final report provides useful information about the performance of nonintrusive technologies and gives specific information on which technologies are best suited for particular data collection needs (*51*).

Passive and active infrared sensors are typically installed on a bridge, pylon, or mast arm and can count volume, speed, and classification data for multiple lanes simultaneously. Passive devices measure the radiated infrared energy from the detection zone by comparing the vehicle temperature with that of the background environment (*52*). Active infrared sensors measure the time it takes a laser beam to travel from the device to the roadway and back (*52*). If a vehicle is in the roadway, the time will decrease, thus indicating its presence. Infrared detectors sometimes have difficulty taking measurements in heavy rain or snow (*53*). Passive detectors were tested in Minnesota at both intersections and freeway applications, while active detection was only tested on freeway. Both test scenarios showed good potential for detecting traffic (*51*).

Doppler microwave radar devices send a low-energy microwave radiation signal to the detection area. A change in this signal indicates the presence of a moving vehicle and determines its speed (*52*). Radar can have trouble detecting vehicles that are close together, but is not affected by weather (*53*). Doppler microwave detectors were tested at freeway sites with good potential for detecting traffic and measuring the speed of moving vehicles (*51*). The performance of these detectors at intersection test sites was poor (*51*). Radar devices that do not use the Doppler Effect send high-frequency radio waves toward the detection zone and calculate the delay. These devices can detect stationary vehicles, whereas the previous type could not.

Ultrasonic detectors send ultrasonic sound energy to the roadway and measure the amount of time for the signal to return to the device (*52*). A vehicle is counted when the time for the sound energy to return is less than normal. Pulse ultrasonic technologies have good potential for detecting traffic at both intersection and freeway applications (*51*). Passive acoustic detectors also use sound waves; however, they detect the sound of a vehicle passing through the detection zone with a series of microphones (*52*). This device uses preprogrammed sounds generated by contact between the pavement and tires to identify the classification of each vehicle (*52*). Passive acoustic detectors were found to only have a moderate potential for detecting vehicles in intersection and freeway applications (*51*). Temperature, wind turbulence, and snow may affect the data collection capabilities of these devices.

Video image detectors use a closed circuit television system to count the number, speed, and type of vehicles passing the detection zone, which may consist of multiple lanes. In addition, cameras can detect traffic incidents by determining changes in speeds. Cameras are mounted in such a way so as to achieve an unobstructed view of the desired lanes to be counted. The accuracy of video detection decreases in inclement weather (*52*). Video requires extensive installation and setup time and is not as accurate as other technologies; however, it has the advantage of offering a wide variety of traffic data (*51*). Additional benefits include side-fire mounting and surveillance options (*51*).

TABLE 8
COST COMPARISON OF TRAFFIC DETECTORS

	Application	
Detector Type	Freeway (per lane)	Four-Way Intersection
Intrusive Detectors		
Inductive-loop detector	$750	$6,000
Nonintrusive Detectors		
Passive infrared sensor	$443	$8,051
Active infrared sensor	$1,293	$14,520
Radar detector	$314	$3,590
Ultrasonic detector	$644	$6,350
Passive acoustic detector	$486	$7,000
Video image detector	$751	$25,000

Source: "Intelligent Transportation Systems Traffic Surveillance" (*54*).

Table 8 compares the approximate costs of each of these nonintrusive traffic detectors with loop detectors when used on freeways or at intersections (*54*). These costs may vary significantly depending on the specific location, number of lanes, installation and labor costs, and vendor. It is interesting to note that despite the lower costs of many types of nonintrusive data collection devices, many agencies still heavily rely on inductive loop detectors (*52*). In part, this may be the result of the comfort of using a technology that has existed and that many agencies have heavily relied on for years. Loop detectors are widely used, simple, and reliable during their life span, whereas many nonintrusive detectors are newer technologies that are still being evaluated by agencies.

The nonintrusive test report (*51*) contains a number of important findings with regard to accuracy for various data parameters and issues to consider in terms of installation and calibration requirements of the devices. Overall, nonintrusive technologies provide a viable alternative to loop-detection and other intrusive technologies for a similar price. The major benefits come from the ability to conduct counts more comprehensively by relying on mobile devices rather than on permanent devices, as well as improving safety and reducing congestion during installation.

Intelligent Transportation Systems

Beginning in 1997, the U.S.DOT Intelligent Transportation Systems (ITS) Joint Program Office (JPO) began tracking the deployment of ITS technologies in 78 major metropolitan areas. Nine ITS infrastructure components have been included in the assessments and, recently, the tracking has included rural deployments and deployments in medium-size cities. The surveyed infrastructure components include: freeway management, incident management, arterial management, emergency management, transit management, electronic toll collection, electronic fare payment, highway–rail intersections, and regional multi-modal traveler information. Information is gathered through a set of surveys distributed to the state and local agencies involved with these infrastructure components. The surveys gather information on the extent of deployment of the infrastructure and on the extent of integration between the agencies that operate the infrastructure. Deployment is measured using a set of indicators tied to the major functions of each component (*55*).

The baseline survey was conducted in 1997, and updates were undertaken in 1999, 2000, and 2002. The 2002 survey also included questions about projected use levels for 2005. Figure 26 provides the 2002 snapshot of summary indicators. With the exception of highway–rail surveillance, all other ITS component areas have seen a growth in deployment, with expectations of continued growth in the future. These trends indicate that a significant portion of our transportation system has the ability to provide data on traffic operations for safety analysis. The following are several findings taken from the summary report (*55*) for the 2002 update:

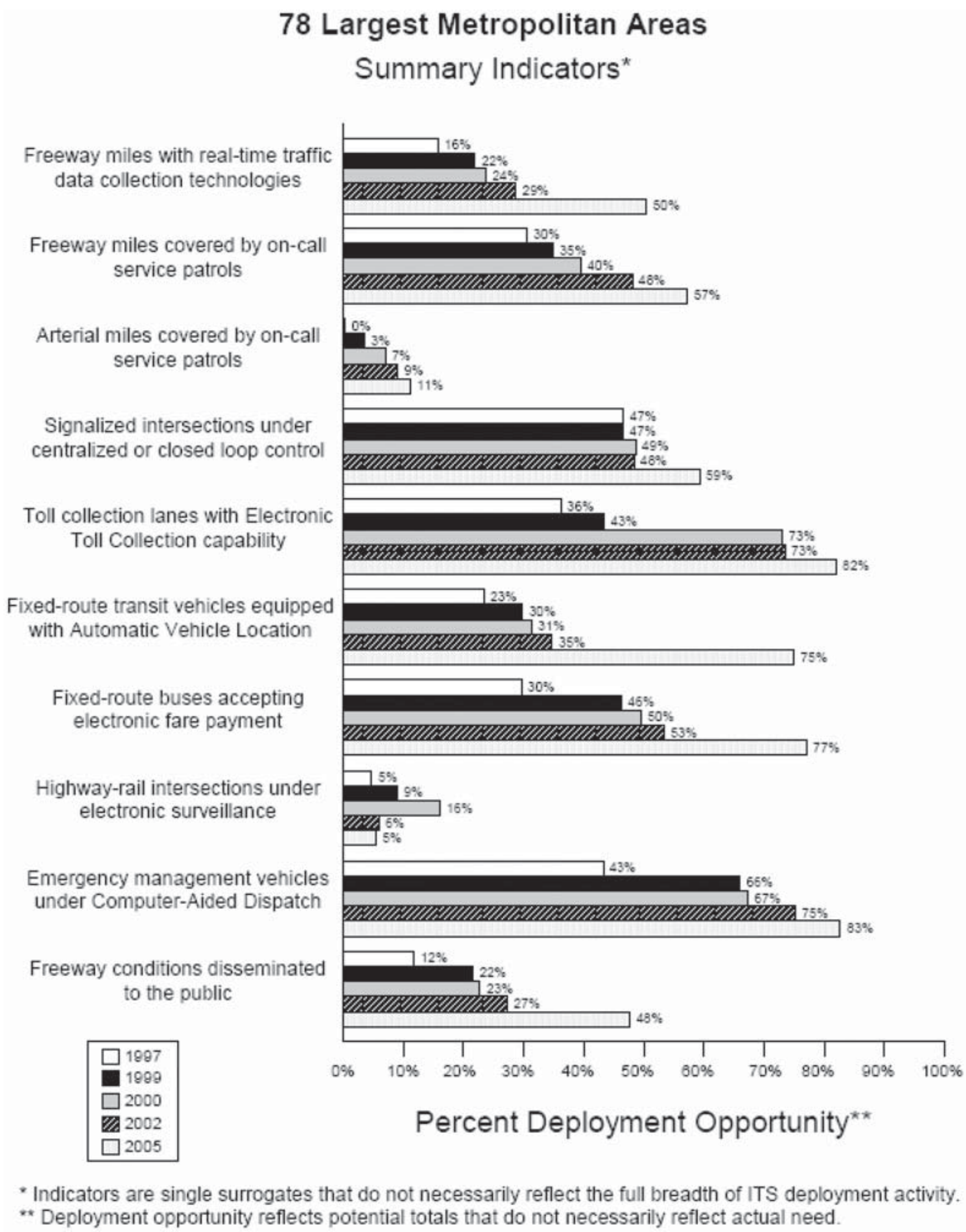


FIGURE 26 Performance measure tracking survey—78 largest metropolitan areas (*55*).

- The highest levels of deployment are observed for emergency management (CAD) and electronic toll collection, which are approaching complete deployment.
- The deployment of arterial incident management lags significantly behind that reported for freeways, but has shown a steady rate of increase for the period of the surveys.
- Transit agencies are deploying technology on a significant portion of their fleets, with a major increase projected for 2005.
- Freeway deployment, in the form of traffic surveillance and service patrols, has been increasing steadily and projections indicate this trend will continue in the future to the extent that more than half of the freeway miles will be covered.

The 2002 survey summary also indicated that nonintrusive surveillance technologies are continuing to gain ground. Figure 27 shows the change in implementation status between 1997 and 2005 for the main technologies, indicating only modest gains in loop-detection deployments. Additional data reports are available for special areas such as arterial safety, and data for individual states may also be obtained from the ITS–JPO website. The safety report (*56*) indicated that relatively few technologies were being deployed to improve the safety of arterial streets. The following three safety questions are of relevance to this synthesis of technology:

- Do you use electronic devices to collect pedestrian data? (33 of 308, or 11%, responded "Yes," with pushbuttons being favored).
- Do you use electronic technologies to improve the safety and mobility of pedestrians? (77 of 305, or 25% responded "Yes," with countdown signals and in-pavement lighting being favored).

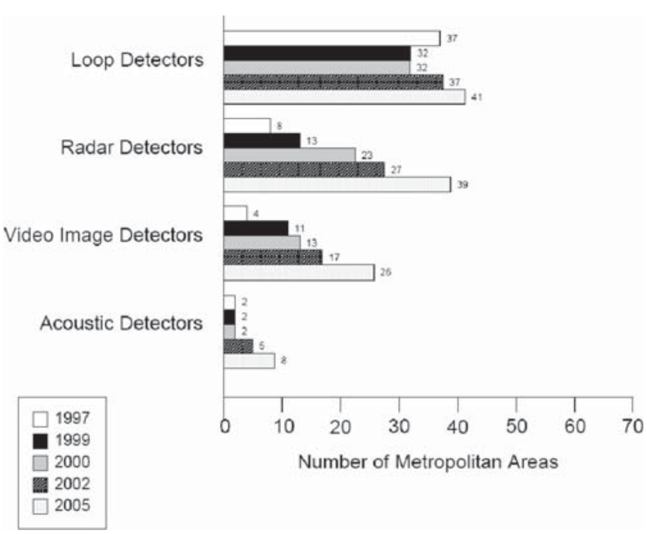


FIGURE 27 ITS technology implementations in metropolitan areas from 1997–2005 (*55*).

- Does your agency use automated enforcement in facilities under its jurisdiction? (30 of 304, or 10% responded "Yes," with red-light running and speeding cameras being favored).

Another report (*57*) completed for the ITS–JPO provides comprehensive coverage of most of the technologies available for ITS deployments. The document is an excerpt from a compendium report that looks back on the first 10 years of the National ITS Program to examine which ITS technology applications were successful, which were not successful, and what the underlying factors are that determine success versus failure. An excerpt from a summary table in the report is shown in Table 9. This document examines cross-cutting technologies for surveillance and communications, as well as programmatic issues, such as planning and analysis tools, archived data, standards, and architecture. Although the report is a few years old, it remains comprehensive in its coverage and valid in its evaluation of technology success. Few technologies have been added since the time of the publication.

The benefits of ITS technology deployments are many. So many, that the ITS–JPO dedicated a website (http://www.itsbenefits.its.dot.gov/) to showcase benefits obtained through ITS technology studies. Additional information is also available regarding costs. Some examples of benefits related to safety include:

- Automated pedestrian detection systems that prevent vehicle–pedestrian conflicts; reducing dangerous crossings at crosswalks by 81%.
- Dynamic message signs that warn drivers of high winds and harsh driving conditions can reduce traffic speeds by 16% and improve uniformity of traffic flow.
- Freeway management systems that detect congestion, initiate lane controls, and warn drivers of slow traffic can decrease accident rates by 23%.
- Maryland incident management system that cuts incident duration by more than half in the Baltimore–Washington region.

Given the numerous potential technologies available for deployment and the associated benefits and costs, analyzing an array of implementation strategies can be a difficult task. FHWA recognized this difficulty and, in 1997, initiated a program to assist public agencies and consultants in integrating ITS in the transportation planning process. ITS Deployment Analysis System (IDAS) software, developed by FHWA, can be used in planning for ITS deployments. State, regional, and local planners can use IDAS to estimate the benefits and costs of ITS investments. IDAS currently predicts relative costs and benefits for more than 60 types of ITS investments. IDAS provides users with the following capabilities:

- Comparison and screening of ITS alternatives,
- Estimation of impacts and traveler responses to ITS,

TABLE 9
EXCERPT FROM ITS TECHNOLOGY SUMMARY

Technology	Sensor and Surveillance Technologies		Comments
	Deployment Level	Limiting Factors	
Cell phones for incident reporting	Widespread deployment	N/A	Successful
Cell phones for emergency notification	Limited deployment	Relatively new; mostly sold in new vehicles—takes long time to reach 30% of vehicle fleet	Successful—number of equipped vehicles growing rapidly
GPS for position, determination, automatic vehicle location	Moderate deployment in fleets (transit, trucking, emergency vehicles)	N/A	Successful—use continuing to grow
Video surveillance	Widespread deployment	N/A	Successful
DSRC (toll-tags) for travel time data	Limited deployment	Mostly used only in areas with electronic toll collection. Requires power and communication to readers	Successful—holds promise
Direct link between Mayday systems and public safety answering points	Limited deployment	Still in research and test phase, significant institutional policy and technical issues	Jury is still out—no known deployments
Cellular geo-location for traffic probes	Limited deployment	New technologies just beginning field trials	Jury is still out—older technology unsuccessful

Source: McGurrin (*57*).
N/A = not available; DSRC = Safety Research Center.

- Estimation of life-cycle costs,
- Inventory of ITS equipment and identification of cost-sharing opportunities,
- Sensitivity and risk analysis,
- ITS deployment and operations and maintenance scheduling, and
- Documentation for transition into design and implementation.

The latest version of the software, IDAS 2.3, was released in November 2003 and can be found online at http://idas.camsys.com/.

Although there are many safety benefits associated with using ITS system technologies (i.e., reduced congestion, improved traffic flow, fewer crashes), the main benefit of ITS systems for safety analysis is related to the data archives that are generated by such systems. Hu et al. (*19*) defined a number of data elements and potential uses including:

- Traffic volume—establishes the relationship between traffic volume and crash occurrence.
- Traffic speed—establishes the relationship between traffic speed and crash occurrence.
- Vehicle classification—quantifies the impact of traffic mix on crash occurrence.
- Incident—determines the impact of incidents on crash occurrence.

However, the relationships that could potentially result from the use of archived data would be limited to areas with active ITS infrastructure and archival processes. Perhaps the main reason that these systems have not been heavily used for safety analysis is because they tend to be placed on major freeways in urban areas, which in terms of crashes are not the worst facilities. Additional information on archived data will be provided in the Traffic Operations Data Management Section to follow.

Nonstandard Data Sources

There is a continuing need for better exposure data. Available exposure data usually consist of traffic volume data collected from a large number of locations within each state and a limited number of vehicle classification counts. There is little or no exposure data on individual driver groups or pedestrians. Future innovations in data collection might include collection of vehicle-based mileage through annual vehicle-inspection odometer reports or driver-license odometer reports. Unfortunately, not all cities and states have EPA requirements for implementing inspection and maintenance programs—only those that are in nonattainment areas must comply. Furthermore, requiring an odometer check with driver's license brings up the issue of vehicle ownership and vehicle sharing.

Another potential source of data comes from instrumented vehicle research studies such as the Commute Atlanta Study (*58*) sponsored by FHWA. In this study, 500 vehicles are equipped with an after-market device that records the position and time for every second of vehicle operation. The limited sample size precludes these data from being widely used to determine mileage, but does allow researchers to check assumptions made about travel patterns within age groups and across sociodemographic backgrounds. Although these data sources are not perfect, there is a potential to supplement the existing spot volume data.

CRASH DATA PROCESSING TECHNOLOGIES

Document Scanning

Government records are subject to preservation laws determined by the state, as well as public record acts. Crash records are no exception. These records must be maintained for purposes of litigation and public safety analysis. In recent years, state agencies have been scanning crash record documents to convert paper or microfilm archives into paperless electronic systems that allow easier access to multiple offices and agencies through existing Internet or intranet connections. This movement has spurred a debate among many archivists as to whether "to scan or not to scan" given the records management requirements. The retention period for a record applies to the record regardless of the medium in which it is maintained. Electronically stored data used to create in any manner a record or the functional equivalent of a record must be retained, along with the hardware and software necessary to access the data, for the retention period assigned to the record. The exception to this rule applies when backup copies of the data generated from electronic storage are retained in paper or on microfilm for the retention period.

To date, microfilm still provides the highest-resolution, longest-lasting media available for record storage (*59*). Properly prepared microfilm has a storage life of 100–200 years with proper storage conditions (*59*), whereas pressed commercial disks may have a lifespan of 100 years and writable media may provide only 7 to 30 years depending on the quality of the disc (*59*). Additional concerns for digital media include the longevity of technology required to read media and the availability of the media itself. Although microfilm is a permanent, eye-readable media, digital media requires a computer and software to be read. Computers have come a long way in the last few decades, and at times new media technology is replaced as quickly as it is introduced. Therefore, although the media may last 7 to 30 or even 100 years, the technology to read it may be obsolete in a much shorter time. Despite these concerns, digital imaging is preferred, by far, for its innate ability to provide widespread access to records.

The Washington State DOT (WSDOT) recently completed a crash report scanning project that resulted in process efficiencies with the ability to generate up to $4 million per year in additional revenue. WSDOT inherited the paper-based crash reporting system from the Washington State Patrol and proceeded to completely overhaul the system. After developing detailed business process documents and specifications for equipment, resolution, and data storage, the system was put out for bid. The upfront attention to detail ensured a successful system implementation. The solution includes a document capture system to scan or convert paper crash reports to electronic TIFF documents. The reports are made available to the public one to two days after receipt, and city and county engineers receive jurisdictional data once per month. With the previous system it took four weeks to process public requests for reports, and city and county engineers had not received jurisdictional data in more than five years. Owing to the increased efficiency of this document management system, it also is helping the agency raise extra revenue. WSDOT estimates it is now collecting between $3 and $4 million annually for damage to state-owned property that it was previously unable to obtain. With the previous paper-based system it took too long to get the paper reports for a specific accident; therefore, by the time the DOT determined the party responsible for damage to roadside hardware and signage the insurance case would be closed. WSDOT plans to integrate new capability to receive electronic crash reports within the next two years (*60*).

Digital imaging is defined as the ability to capture, store, retrieve, display, process, and communicate or disseminate records electronically using a variety of hardware and software components. With proper planning and design, agencies can significantly improve business operations without endangering business processes when technologies become obsolete. A number of guidance resources exist, as well as several American National Standards Institute (ANSI) and Association for Information and Image Management (AIIM) recommended practices. The National Archives website (*61*) contains a Toolkit for Managing Electronic Records. The Toolkit is a web portal that provides summary descriptions of a collection of guidance products for managing electronic records and resources ("tools") that have been developed by the National Archives and Records Administration and other organizations. In addition, many states maintain their own guidance documents for imaging. These guidance documents often reference ANSI/AIIM standards. The following points of guidance were developed by the Nebraska State Records Administrator (*62*):

- When determining document scanning resolution, agencies should consider data storage requirements, document scanning throughput rates, and the accurate reproduction of the image. Vendor claims should be validated using a sampling of the agency's documents. Calibration and maintenance of the scanners should meet the manufacturers' recommended schedule. The minimum resolution for black and white standard text office documents is 200 dots per inch (dpi), and drawings, maps and plans should be scanned at a minimum resolution of 300 dpi.
- The system should provide techniques for monitoring and reporting verification of the records stored on a digital optical disk, and the system administrator should actively follow the status of the monitors. The system should comply with ANSI/AIIM MS59-1996, "Media Error Monitoring and Reporting Techniques for Verification of Stored Data on Optical Digital Data Disks."
- Agencies should use a nonproprietary digital image file format or provide a bridge to a nonproprietary digital image file format. A standard definition for file formats is found in ANSI/AIIM MS53-1993, "Standard Recommended Practice, File Format for Storage and Exchange of Images, Bi-Level Image File Format, Part 1," or open published standard file formats, such as the Adobe Portable Document Format (PDF), HyperText Markup Language (HTML), or Extensible Markup Language (XML).

- The query interface for the indexing database should meet the requirements of Federal Information Processing Standards Publication 127-2, "Database Language SQL." The purpose of this publication is to promote portability and interoperability of database application programs.
- The agency should establish operational practices and provide technical and administrative documentation to ensure the future usability of the system, continued access to long-term records, and a sound foundation for ensuring the system's legal integrity. Procedural controls should reflect requirements for the legal acceptance of records as outlined in AIIM TR31-1992, "Performance Guideline for the Admissibility of Records Produced by Information Systems as Evidence."
- The agency should perform a visual quality control evaluation of each scanned image and related index data. When the system is operational, the agency should perform a weekly scanning quality test that complies with ANSI/AIIM MS44-1988 (R1993), "Recommended Practice for Quality Control of Image Scanners."

Wireless Data Communications

Wireless communications and data transfer capabilities have changed immensely over the last decade. Starting with analog technologies, which were limited to approximately 56 kbps maximum throughput, technologies have become increasingly more efficient and cost-effective, with the new Edge technology approaching broadband throughput levels. The evolution has included such wireless technologies as analog, Code Division Multiple Access (CDMA), Time Division Multiple Access (TDMA), 900 MHz, Global System for Mobile Communications/General Packet Radio Service (GSM/GPRS), Enhanced Data Rates for GSM Evolution (Edge), 802.11 a/b/c/g/p, Bluetooth, and satellite service.

Today, numerous wireless technologies and communications platforms exist to provide communications services at or below the cost of landline communications. In terms of data collection and data sharing, these technologies have changed the way many agencies operate. For example, in Iowa, Maryland, and New York, police crash reports can be sent electronically directly to the crash records database from the police vehicle. Considering that these reports are typically handwritten at the crash site, keyed at the police agency, mailed to the public safety agency, keyed at the public safety agency, transferred to the transportation department, and handcoded for crash location by the transportation department—a process taking 2–6 months and sometimes longer—newer electronic crash reporting systems provide data almost instantaneously.

Aside from the efficiencies that wireless technologies provide, they also provide means for better data linkage capabilities. One interesting wireless communications project, CapWIN (Capital Wireless Integrated Network) (*63*), was undertaken in the National Capital Region. CapWIN created the first multistate, interoperable, public safety, and wireless data system in the United States to provide a single, open, shared, and secure system for the public safety community. The project allows users to access communications and data networks using an array of technologies including personal digital assistants, in-vehicle computer systems, and standard in-office desktop computers. Although the project benefits large police agencies, the biggest benefit occurs for smaller jurisdictions that would not be able to afford such a system on their own. The purchase of mobile data computers and wireless connectivity is all that is required to use the resources of the wireless data network. CapWIN includes several current applications:

- Access to operational data and resources, including multiple state and federal law criminal databases;
- Incident management and coordination across agencies, regions, public safety sector, and transportation disciplines;
- A searchable directory of individual first responders; and
- Secure one-to-one and group public and private discussions.

Future capabilities of the system are expected to include:

- Multistate sharing of local criminal data not available through the National Crime Information Center;
- Transportation system integration including remote video, incident logs, road sensors, etc.;
- CAD data exchange across jurisdictions and public safety disciplines;
- Advanced GIS capabilities including incident/user GPS identification, aerial photograph overlays, etc.;
- Voice-over Internet Protocol; and
- Secure e-mail.

Projects such as the CapWIN can provide safety analysts with additional confidence in data, because mobile computers can access and import data directly from databases. Thus, data elements that provide linkages to other data sources are more reliable and will therefore lead to more complete linkages and analytic capabilities.

Geographic Information System

A GIS combines hardware and software to manipulate, manage, and store information that can be associated with spatial features. GIS platforms are well-suited for use in transportation data processing, management, and analysis, because road networks are inherently spatial in nature. GIS systems allow for multiple layers of data to be queried for spatial relationships and trends. GIS has been used in transportation planning activities, pavement and bridge maintenance programs, and traffic operations studies. However, few states are using GIS extensively for crash data analysis.

Researchers at UNC–HSRC developed a GIS-based highway safety analysis tool (*64*) using HSIS data for North Carolina—specifically Wake County. The tool combined multiple types of data including crash, roadway inventory, signal inventory, pavement management and condition inventory, railroad grade crossing inventory, and traffic operations volume files. Additionally, population and demographic information from TIGER (*T*opically *I*ntegrated *G*eographic *E*ncoding *R*eference) census files were also included. The tool was developed using ArcView GIS and ARC/INFO. The system allows data to be entered, edited, analyzed, and exported to other applications. Incorporated into the system is the ability to view scanned crash reports and video-log images. The analysis tools include five separate programs to evaluate crashes at designated spots or intersections, along specific roadway segments, clustered around a specific feature, or within a defined analysis corridor.

The GIS-based crash referencing and analysis system provides the capability to identify problem areas visually, as well as evaluate countermeasures. Research at UNC–HSRC (*64*) determined that a GIS-based system provides a number of advantages over traditional computerized analysis systems. It can

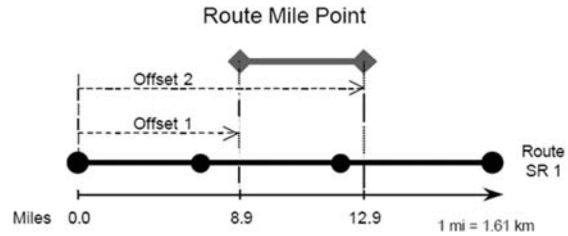
- Edit crash locations quickly with GUI,
- Evaluate problem locations using spatial graphical displays,
- Produce graphics and descriptive plots of crash data,
- Incorporate GPS for more reliable data,
- Conduct corridor analysis by linking adjacent routes, and
- Incorporate nontraditional geographic data sources such as census data.

The implementation of a GIS requires a significant level of understanding of GIS requirements, linear referencing systems, and GIS-based highway safety data analysis tools. In 2001, UNC–HSRC and GIS/Trans, Ltd. conducted a study (*65*) to determine the level of use and methods for integrating GIS by HSIS states (California, Illinois, Maine, Michigan, Minnesota, North Carolina, Utah, and Washington). Subsequently, Maine and Washington were selected as case study states to provide a detailed account of integration requirements.

The final report is a must-read for any agency or safety office considering a GIS implementation (*65*). Over the years, a multitude of linear referencing systems for roadway inventory data have been established. The two most common forms are the route-milepost shown in Figure 28 and link-node systems shown in Figure 29. Each has its own advantages and disadvantages and can effectively be incorporated into a GIS. The goal of the research was to initiate a "common dialogue" between GIS professionals and traffic safety engineers, whereby teams can develop a successful GIS-T infrastructure to support safety analysis. The document highlights several areas of GIS development including:

- Benefits that GIS technology offers for analysis;
- Description of the historical safety data, linear referencing systems used by these data, and differences between linear and spatial data;
- Background on linear reference systems including types of systems and use of these systems in GIS; and
- Understanding of GIS management including resolution, scale, and calibration (*65*).

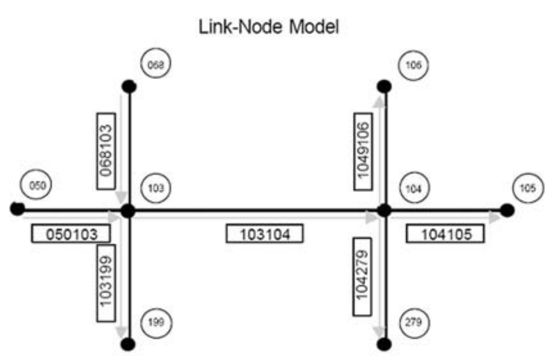
The researchers used the two case study states, Maine and Washington, to portray different types of linear referencing systems and the implications to GIS development.



Surface Condition Database

Route	Begin MP	End MP	Condition
SR1	8.9	12.9	Good

FIGURE 28 Route-milepost linear referencing method (*65*).



Route Section Database Table

Link ID	Begin Node ID	End Node ID
050103	050	103
068103	068	103
103104	103	104
103199	103	199
104105	104	105
104106	104	106
104279	104	279

FIGURE 29 Link–node linear referencing method (*65*).

ROAD INVENTORY PROCESSING TECHNOLOGIES

Computer-Aided Dispatch

Safety analysis tools such as IHSDM require a significant amount of detailed data regarding the geometric alignment of roadways. One of the best sources for this type of data is the CAD design drawing. Unfortunately, many years ago, designers did not have such electronic CAD programs; therefore, many of our roads come with hand-drawn plans. A great resource exists today for the data systems of tomorrow.

Many of the new versions of CAD programs also have a mapping component (i.e., Microstation/Geomedia and AutoCAD/Maptitude). From existing design drawings users can create maps that can be exported to other mapping programs or these programs can accept data and be used as the primary mapping application. Data can be imported from Open DataBase Connectivity (ODBC)-compliant data sources such as Access, Oracle, or SQL server. Additionally, raster images such as satellite imagery and aerial photographs can be imported as reference data or for use in editing or creating geographic files.

The integration of CAD and GIS mapping software provides a powerful tool for the generation of precision mapping. The more data that are generated from design drawings at project implementation, the less data agencies will need to collect. A proactive stance with processing and maintaining mark-up and as-built data files will save extensive labor resources in the future. In addition, a common export language, XML, has been designed to allow portability of files for the future. XML was developed to store information inside documents in such a way that the data maintains a structured organization, and at the same time allows portability among different platforms—similar to HTML used in web development. The formal definition and specifications are developed by the World Wide Web Consortium (www.w3.org), which "develops interoperable technologies (specifications, guidelines, software, and tools) for data exchange among the web. XML was designed to be both hardware- and software-independent. Simply stated, XML documents are human-readable text documents. Nearly all current CAD programs allow data files to be exported in XML format. Furthermore, analysis tools such as IHSDM import XML files directly, with no further manipulation required.

Inventory Automation Software

Previously, a number of instrumented vehicle technologies were described along with their benefits for data generation. These technologies included video-log, GPS data collection, and roadside scanning. Although many of the technologies produce data directly, some do not and capture images that must be interpreted and manually logged by an analyst. For example, the use of video-log to objectively identify sign type and location as well as subjectively estimate roadside hazard ratings along a road currently requires a manual process.

The integration of GPS data streams with other information can provide a bridge for the automation of data extraction within a GIS system. If data are captured relative to position, automation software can be developed to "play back" images or data and analysts can add features directly on the screen, which identifies an element relative to a specific position. Automation software has been used extensively in the development of pavement management systems, because a human in the loop best determines some data elements. Figure 30 shows an example of such a setup. Automation software is generally developed for specific data collection purposes; however, most software packages would allow extensions for other uses (i.e., an automation package designed to record crack inspection may also be used to log pavement marking status).

Road characteristics data collection is a tedious, time-consuming task. Tsai et al. (*66*) have been working on a number of automation methods to reduce these time-consuming tasks. To enhance the road characteristics data collection processes, a series of cutting-edge, image feature, extraction algorithms and applications have been developed to automatically extract roadway characteristics such as signs (stop sign and speed limit) and pavement geometric properties using video images. A case study using video-log images with a resolution of 1300 $\times$ 1024 from a Georgia roadway demonstrates the capability of image feature extraction technology. The 200 images are batch processed in less than 3 min using a Pentium-IV 3.06GHz central processing unit.

The main benefit of automation software is the increased capability to process data more efficiently without duplication of data keying. Integration of GPS in initial data collection allows processed data to be related directly with other data sources in a GIS platform.

FIGURE 30 Pavement monitoring post-processing workstation.

CRASH DATA MANAGEMENT TECHNOLOGIES

AASHTOWare—Transportation Safety Information Management System

A comprehensive TSIMS is under development as part of the AASHTOWare Joint Software Development Program. The purpose of the system is to provide users with a universal interface for all of the transportation safety data within a state; providing data at both the state and local levels (*67*). Originally started in 1999, the TSIMS project underwent a substantial scope change after the initial Phase I project uncovered a complex system of safety data, data linkages (or lack thereof), and data owners.

TSIMS is envisioned as an enterprise data warehouse that will capture data from multiple subsystems, establish linkages between data, and prepare data for analysis. Data subsystems currently included in the scope are traffic crash, vehicle registration, driver license and history, roadway, emergency medical services and trauma, and traffic citation and conviction data (*67*). The data may be stored in an internal relational database or captured through interfaces with existing systems. TSIMS is not intended to replace existing data collection systems, but rather to provide a common interchange format for use with TSIMS analysis modules as well as external analysis programs such as SafetyAnalyst (*68*). The core TSIMS software will provide (*68*):

- A consolidated data warehouse of safety information based on national data standards and best practices, including ANSI D.16, MMUCC, and CODES.
- Data import utilities to populate and maintain the data warehouse from data maintained in existing state information systems.
- Data translation facilities to translate data formatted according to existing information systems methods into a uniform TSIMS format.
- Data analysis and reporting capabilities that will enable safety personnel to query, report, and analyze the data, supporting the identification of trends, high hazard locations, and causal relationships between the observed crash reports and other related safety information.

TSIMS has completed Phase 1 of the project and is working on Phase 2 as of October 2005. The Phase 2 TSIMS project scope includes the final design and development of the core TSIMS product. This product will provide a consolidated data warehouse, data import utilities, data translation facilities, and data analysis and reporting capabilities. The Phase 2 project also proposes a variety of discretionary system components that can be developed to increase the functionality and technology that TSIMS imparts. Included among these discretionary components are the crash locator module, linear reference translator, and web data services interfaces (*69*).

Middleware

Middleware consists of software agents that connect multiple disparate application components. It is used most often to support complex, distributed applications. For example, many DOTs maintain separate applications for roadway inventory information management and railroad crossing information management—middleware may be used to connect these two disparate applications to produce queries for federal reporting requirements. The applications may be developed and maintained separately; however, middleware acts as an intermediary between the two application components. Middleware technology allows for interoperability between applications that otherwise would not have linkages between them.

Middleware is now used to describe web servers, application servers, content management systems, and similar tools that support the application development and delivery process. Middleware is especially integral to modern information based on XML, SOAP (Simple Object Access Protocol), web services, and service-oriented architecture. For middleware to be helpful, an organization must carefully select which functions and linkages are needed for that individual agency. Costs vary according to which vendors and which middleware products are chosen. An agency may choose to develop its own middleware or may depend on a vendor for development and maintenance support. Ultimately, middleware is the enabling technology of Enterprise Application Integration (EAI).

Enterprise Database Applications

EAI is the use of software and computer systems to bring together (integrate) a set of enterprise computer applications. Enterprise computer applications allow employees to perform business functions such as accounting, project scheduling, information tracking, and project maintenance. EAI has been gaining in popularity among transportation agencies for the last 2–3 years because, traditionally, enterprise computing often takes the form of islands of automation. These islands are common in DOTs across the county and are mostly associated with divisions in business functions within the DOTs—from each business function comes another database application. The value of these individual applications is not optimal, primarily because they are managed in isolation. Integration can add value across an enterprise network when new users can take advantage of existing resources rather than duplicating efforts. This requires enterprise applications to be available on internal or external networks. However, if integration is applied without following a structured EAI approach, many point-to-point data connections develop across an organization to support ad hoc functions. When dependencies are added on an impromptu basis, the result is tangled and difficult to maintain.

Owing to the spatial attributes of most transportation data, a common application platform for enterprise integration is

GIS. Several GIS platforms are available for development including ArcGIS, Geomedia, and Maptitude. A number of good examples of such enterprise applications exist and include Georgia Transportation Explorer (TREX) (an in-house development), Oklahoma Geographical Resource Intranet Portal (GRIP), and South Carolina Roadway Inventory Management System (RIMS) (both developed by consultants).

Georgia's TREX is a web application that was developed by the Georgia DOT Division of Information Technology to connect enterprise databases throughout the department (*70*). The two databases that are connected for external viewing are Transportation Projects and GIS; however, many other databases are linked through the program for internal DOT use (*70*). The external version allows viewing of Transportation Projects, accessed through a searchable map connected to the Georgia DOT GIS. This application supports viewing of maps, reports, and plans, as well as real-time database queries. Various layers may be turned on or off, including projects, traffic, rail, air, transit, natural resources, roads, traffic volumes, and boundaries. Results for transportation project searches are listed on the right-hand side of the screen, showing preconstruction and construction projects. Figure 31 shows TREX with information from two projects that were selected using the GUI.

Since 1990, the Oklahoma DOT had used GIS to manage transportation information; however, efforts were fragmented across different DOT departments. Each division was maintaining its own database, and information was not being shared across divisions. With the responsibility of trying to amass data from multiple divisions, the Planning and Research Division of the Oklahoma DOT began the development of a centralized GIS, where data from all divisions could be stored and accessed. The objective was to enable fact-based decision making during emergency and normal daily operations, and to provide all Oklahoma DOT divisions with access to department-wide transportation information with geographic mapping capabilities.

In 2003, the Oklahoma DOT hired a consultant to develop GRIP. GRIP was envisioned as a window into all the transportation data housed by various division databases. The purpose of this application is to provide consistent viewing, reporting, and analysis of business data so that more informed decisions can be made about how to improve the quality and safety of Oklahoma's transportation network. GRIP did not replace individual databases; instead, it created a data warehouse populated through periodic data retrieval from legacy databases. In total, 13 databases are currently integrated in the GRIP enterprise application. The Oklahoma DOT's business data layers include information on bridges, pavement management, needs study, crashes, roadway inventory, programs and projects, HPMS, at-grade railroad crossings, and speed zones. Figure 32 shows the interface with multiple database connection options across the top of the GUI. The development to date has cost $1.4 million. The Oklahoma DOT noted several benefits of the system including (*71*):

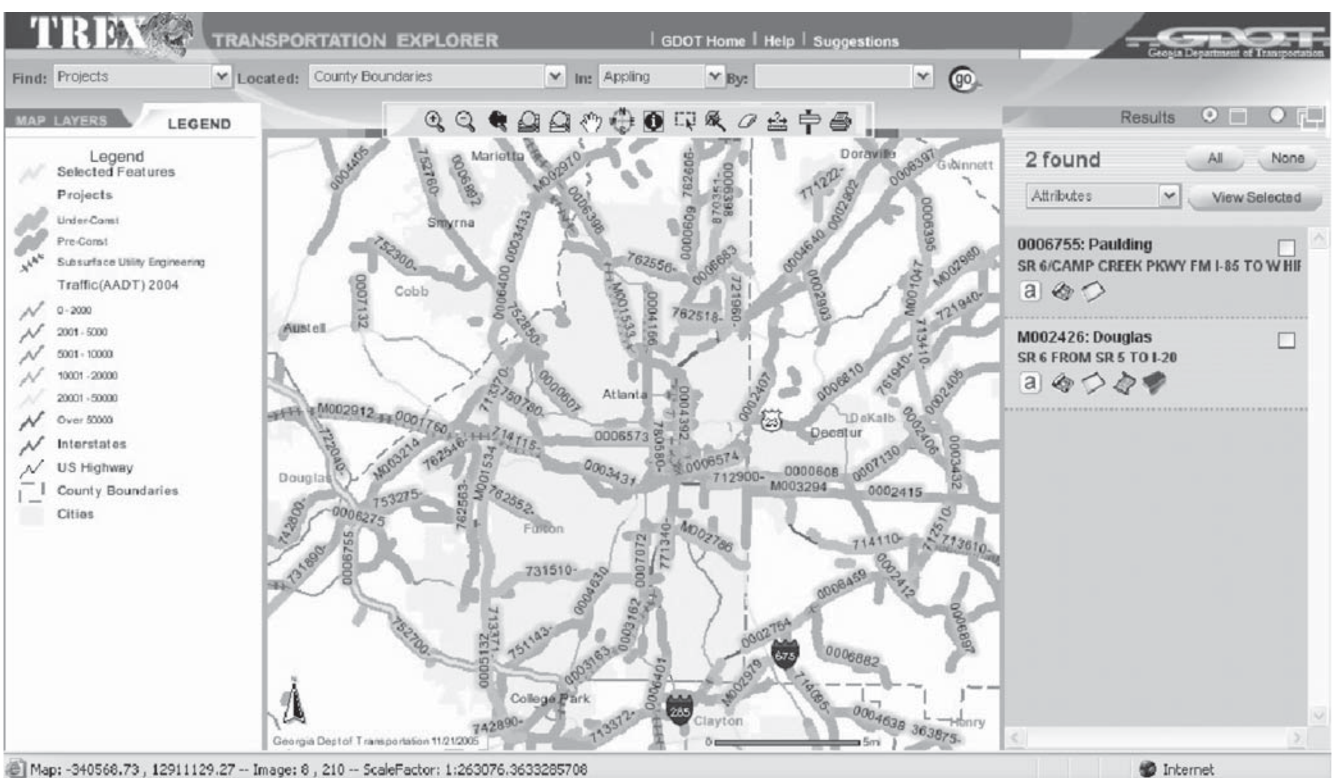


FIGURE 31 Georgia DOT Transportation Explorer (TREX) Internet application.

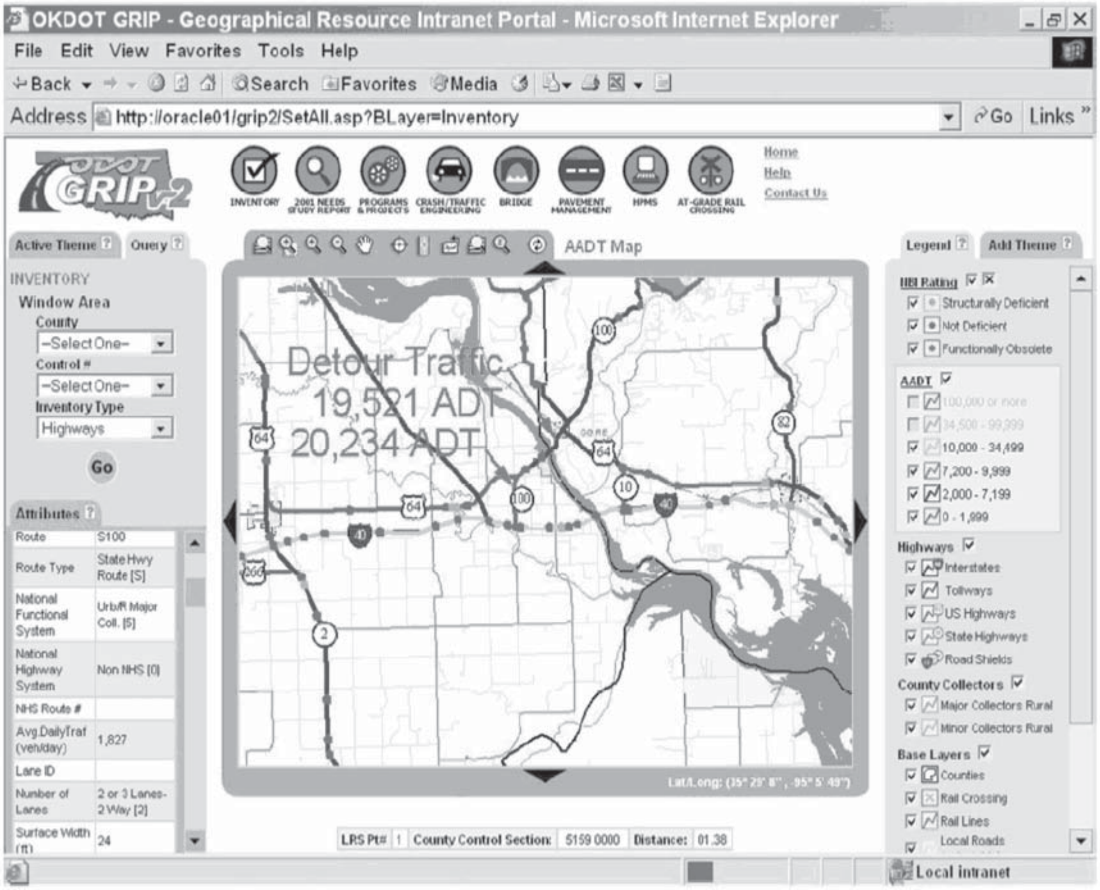


FIGURE 32 Oklahoma DOT Geographical Resource Intranet Portal (GRIP) application.

- Increased efficiency among departments—employees have access to accurate, timely information relating to the entire transportation system.
- Significant reduction of costs associated with staff dedicated solely to creating maps.
- Information requests can be handled in minutes instead of days.
- Access to useful information from 13 databases in an integrated application translates into better and faster decision making.

SCDOT also hired a consultant to develop an enterprise solution to replace the legacy mainframe application used to manage roadway inventory data. RIMS is Oracle-based and allows users to build queries against multiple tables maintained in the RIMS database. Within RIMS, enterprise access is provided with a geospatial interface to information from the Roadway Information System, Pavement Management System, Highway Maintenance Management System, AASHTO's SiteManager, and department financial information. In addition, RIMS includes a built-in viewer that allows users to view SCDOT's entire database of Photolog images. Another project developed for SCDOT is a Hurricane Evacuation Decision Support Solution. The solution integrates map-based data for evacuation routes, vehicle counts, road closures, and weather conditions, and distributes them on the enterprise network to key personnel coordinating evacuations in times of natural disaster (*72*).

ROAD INVENTORY DATA MANAGEMENT TECHNOLOGIES: AASHTOWARE

AASHTOWare is a sophisticated group of software products developed by AASHTO through the joint development process. This process allows members to receive optimum software solutions for a fraction of the cost of custom in-house development, while promoting a best practices approach to design. The joint development process offers numerous benefits, including customizable features and cost sharing. The process is user-led and is administered through AASHTO with a user-based task force and a dynamic user group. License fees make funds available for maintenance, support, and enhancements to maintain the technology and functional requirements of the system (*73*).

Two AASHTOWare software solutions developed under the joint development process, Trns*port, an existing project management program, and TSIMS, a safety data management program that is under development, were mentioned previously in this report. However, several other AASHTOWare products exist and are worthy of mentioning as a result of their ability to help maintain information on multiple components of infrastructure and operations (*74*):

- Pontis—a comprehensive bridge management system. Pontis stores bridge inventory and inspection data, formulates network-wide preservation and improvement policies for use in evaluating the needs of each bridge in a network, and makes recommendations for what projects to include in an agency's capital plan for deriving the maximum benefit from limited funds. Pontis supports the entire bridge management cycle, allowing user input at every stage of the process. The system stores bridge inventories and records inspection data. Once inspection data have been entered, Pontis can be used for maintenance tracking and federal reporting. Virtis and Opis are new products that support bridge design and load rating analysis. All three bridge products are designed to work together seamlessly.
- SDMS—a survey data management system developed to collect, verify, reduce, edit, translate, and establish survey data as it relates to survey points and lines. SDMS is a combination of the SDMS Collector, the field data collection component, and the SDMS Processor, the survey data review and reduction component.

The continued development of AASHTOWare programs helps to ensure common data formats nationally as well as reduce the cost of the solutions making them more widely applicable.

TRAFFIC OPERATIONS DATA MANAGEMENT TECHNOLOGIES: COUNT MANAGEMENT SOFTWARE

Within the operations of the DOTs, traffic counts are required for numerous planning and design activities. Some activities require turning movement counts, whereas others require speed, volume, and vehicle classification. Counts may be conducted continuously, seasonally, or only for specific periods during a single day. Continuous counts are usually collected by permanent count stations, whereas short-term counts are collected with mobile or portable devices. Furthermore, the devices are made by a number of different manufacturers—each with its own proprietary software to process the count data. The variability in the length and type of the counts as well as the proprietary formats of the counts make the task of traffic count data management a complex issue.

The Florida DOT developed a software package, Survey Processing Software, in-house to maintain traffic count data. The software has been in use for more than 5 years and is used to process short-term (i.e., seasonal, portable, coverage, noncontinuous) traffic counts and vehicle classification surveys. It processes file formats from a number of types of traffic counters and reformats them to a common format for analysis. Each year, the Florida DOT solicits comments from users and any problems are corrected. Enhancements are made if practical and cost-effective. To date, no evaluations of the software or efficiencies from use of the software have been conducted.

In the survey of states, Missouri and Wisconsin both reported that they use commercially available software, Traffic Data System (TRADAS), to manage count data. TRADAS software is a traffic data collection management, quality control, and analysis software product. Data captured by TRADAS can originate from permanent count sites, short-term counts, traffic management centers, and manual counts (for volume and vehicle classification). TRADAS is a comprehensive system, performing traffic data polling management, site management, quality control, summarization, factor calculation, average annual daily traffic estimation, reporting, and database management. It analyzes multiple types of data including volume, classification, speed, weight, and lane occupancy. TRADAS is Oracle-based with a C++ server and was designed to meet the requirements of a range of traffic monitoring standards and guidelines as follows:

- FHWA—Traffic Monitoring Guide
- AASHTO—Guidelines for Traffic Data Programs
- ITS—National Transportation Communications for ITS Protocol Data Collection Monitoring Standard
- ITS—Archived Data User Service Standard

Both Missouri and Wisconsin indicated that the software and system was efficient and cost-effective (*75*).

CHAPTER FIVE

DATA AND TECHNOLOGY MATRIX

To assist states in using the information contained in this synthesis, a data requirements and technology matrix was developed. Building on the table of data requirements presented in Appendix A, each required data element was assessed to determine if any technologies exist to enhance the efficiency of data collection or processing of the data. Although the data requirements listed in this report are specific to IHSDM and SafetyAnalyst, the matrix could be adopted for other safety analysis tools—assuming that the data elements are similar to those in IHSDM and SafetyAnalyst. A copy of the data and technology matrix can be found in Appendix F.

Table 10 shows a brief excerpt of the matrix for roadside data elements. Within the matrix, data elements are identified as required by either IHSDM or SafetyAnalyst. For SafetyAnalyst, the items are also denoted as required (x) or optional (o). The right-hand portion of the matrix contains a number of potential technologies that can be used to assist in data collection and the processing of specific data elements including highway measurement vehicles, video-logging, electronic crash reporting, GPS, barcode/magnetic strip reader, plan sheet/crash report document scanning, event data recorder, ITS data archives, nonintrusive traffic counters, and satellite imagery. Some data elements can be collected using multiple technologies. The higher the level of automation in the process, the more likely it will produce efficient and accurate data sources. Manual collection methods, such as collecting crash locations using a handheld GPS receiver, provide efficiencies in processing location data, but may not make crash reporting in the field more efficient. Also, manual collection of GPS coordinates is subject to human error, both in initial recording and in the data entry function at the central location. Although the cost of fully integrated GPS receivers with electronic crash reporting in the field is much higher, it should provide for better efficiencies across the data collection, processing, and analysis system. Although the matrix presents information regarding potential technologies, many decisions must still be made by the agency or agencies depending on the magnitude of data collection efforts and the existing system components.

Several steps are proposed to determine which technologies would best serve the state:

1. Establish a safety data task force with multiple levels of representation from data collectors, to users, and management.
2. Determine which safety analysis tools will be used:
   a. IHSDM
   b. SafetyAnalyst
   c. *Highway Safety Manual*
   d. Other.
3. Obtain specific data requirements for the tools.
4. Develop listing of all data elements and data collection methods used to obtain safety data within the state agencies.
5. Identify data element matches between existing and required data elements.
6. Determine whether data elements have similar coding structures as those used by IHSDM and SafetyAnalyst (use websites provided earlier for detailed data descriptions).
7. Identify gaps in data sources:
   a. Which required data elements are not collected?
   b. Which data elements do not match in structure and content?
8. Assess quality and cost of existing data and data collection methods:
   a. Which data are collected with minimal confidence?
   b. Which data collection methods require expensive manual labor?
   c. Which data elements are maintained in redundant locations owing to a lack of ability to share data effectively?
9. Highlight data elements within the data and technologies matrix if data needs were discovered in steps 6–8.
10. Rank order of data needs.
11. Determine which potential technologies exist for each rank ordered data element. (To do this, scan across the matrix to see which technologies are marked for the data elements in question. Most of the data elements have been mapped to one or more technologies.)
12. Assess which technologies will provide the most needed and the largest quantity of data.
13. Identify the hierarchy of automation if more than one technology applies.

With potential technologies identified, the hard part of the process begins:

- If multiple technologies exist, which specific technology should be chosen?
- Which vendor?

TABLE 10
EXCERPT FROM DATA AND TECHNOLOGY MATRIX

Data Category/Type	Data Element	Sub-Element	Data Requirements		Conformity	Potential Data Collection Technologies									
			IHSDM	Safety-Analyst	MMUCC	Highway Measurement Vehicle	Video-Logging	Electronic Crash Report	GPS	Barcode/ Magnetic Strip Reader	Plan Sheet/Crash Report Document Scanning	Event Data Recorder	ITS Data Archives	Non-Intrusive Traffic Counters	Satellite Imagery
Road Inventory															
Roadside	Bike facilities present		x	x			x				x				
	Driveway density		x	o			x								x
	Foreslope	Slope	x			x					x				
		Width	x			x					x				
	Backslope	Slope	x			x					x				
		Width	x			x					x				
	Ditch	Bottom Shape	x			x	x				x				
		Width	x			x					x				
	Obstruction	Offset	x			x					x				
		Presence	x			x	x				x				x
		Side	x			x	x				x				
	Roadside hazard rating		x				x								

Notes: x = required; o = optional.

- What are the costs—including capital, operating, and maintenance?
- What are the system benefits and how can they be measured?
- How do you ensure complete system integration?

Unfortunately there are no routine answers to these questions. The answers are dependent on the status of existing data collection efforts in the state. Most of the technologies provide scalable options. For example, the highway measurement vehicles provide a number of data elements by combining a number of component technologies into one integrated data collection vehicle. The FHWA Digital Highway Measurement Vehicle collects cross slope with an undervehicle-mounted laser and video-log with roof-mounted cameras. If cross slope is important, and video-log is already obtained in conjunction with an existing pavement profiling vehicle, the agency may wish not to include the video components in a new implementation. By far the most efficient solution is to include the maximum number of components into one vehicle. Therefore, the redundant collection of road network data is minimized. Some companies that develop or build the measurement vehicles offer lease services or full-service data collection services. Depending on how much data the state must collect and maintain, one of the latter options may be quite attractive.

Overall, a few items must be considered in the decision to implement new technologies:

- Availability of current and future resources to sustain technology (operations, maintenance, and future upgrades).
- Requirements for initial and ongoing training to support technologies.
- Ability to integrate with existing and planned systems (operating systems, linkages, database connections, etc.).
- Capacity to maintain existing legacy system until full implementation and validation of new technologies have been completed.

Numerous assessments of innovation in government have been conducted over the years providing insights into new program implementations. In 2001, Sanford Borins (*76*) wrote a management series piece for PriceWaterhouseCoopers' Endowment for The Business of Government entitled, "The Challenge of Innovating in Government." The information used to develop the document came from three award programs for public management innovation. The award programs included the United States (Ford–KSG awards), Canada (Institute of Public Administration of Canada, or IPAC, awards), and the countries of the Commonwealth (Commonwealth Association for Public Administration and Management, or CAPAM, awards). The public management innovation awards are judged based on novelty, impact, and repeatability. Quantitative analysis of these award-winning innovations revealed five building blocks of innovation, proven tools for change:

- The use of a systems approach, appearing in approximately 70% of the samples in advanced and 60% of the samples in developing countries.
- The use of new technology, usually new information technology, appearing in between 29% and 57% of the samples.
- Process improvement, appearing in between 35% and 66% of the samples.
- The involvement of organizations or individuals outside the public sector to achieve public purposes, appearing in approximately 30% of the samples.
- The empowerment of communities, citizens, or staff, appearing in between 14% and 30% of the samples.

Included in the Commonwealth survey was a final question asking innovators the most important lessons learned and seeking their advice for would-be innovators.

Table 11 shows the results of this question in terms of the number of times a certain piece of advice was cited. "The advice dealing with planning an innovation emphasizes the importance of learning and incorporates the tension between having a clear vision and improvisation. The advice regarding implementation reflects the tension between being decisive and moving quickly on the one hand, and recognizing the need to build wide support on the other. The advice about process also reflects the importance of staff level innovation,

TABLE 11
LESSONS LEARNED FROM INNOVATION IN GOVERNMENT

Lesson Learned	Times Cited
Make the project exciting for staff	22
Promote program, ensure positive media coverage	21
Make sure program objectives reflect organization's objectives	17
Project manager should be task-orientated	12
Involve the stakeholders	11
Keep regular, ongoing communication	11
Get support from senior management	10
Have a clear idea of the end product	9
Allow staff freedom to innovate	9
Keep implementation team small, with decision-making power	9
Think strategically, consider wider implications	7
Have a champion, take ownership	7
Be dedicated and/or persistent	7
Documentation is tedious but essential	7
Develop adequate control mechanisms, support governance structure with agreements	6
Solicit regular feedback as a motivator, demonstrate early ongoing success	5
Implement quickly to avoid losing focus	5
Learn from your mistakes, don't be afraid to change plans based on information gathered or in response to a changing environment	5
Learn from other innovators	4
Ensure that you have the necessary resources	3

persistence, morale, and upper-level support. The advice includes references to the constraints of operating within the public sector. Given the frequency that resource constraints arise, it is somewhat surprising to see that the least-cited piece of advice was 'ensure that you have the necessary resources.'"

Finally, a well-planned technology implementation strategy is required to achieve program goals. A number of well-known concepts have been used with success including (*77*):

- Encourage management visitations to successful implementation sites,
- Educate leadership and task force members with success stories,
- Pilot technology implementation in controlled setting,
- Develop a phased implementation plan,
- Encourage opt-in of affected agencies through development of a cooperative environment,
- Define measurable goals,
- Set short-term and long-term goals,
- Demonstrate early and ongoing successes,
- Institute policies or develop standards that require technology implementation,
- Reward early adoption of technology,
- Provide ample resources for implementation, and
- Demonstrate continued success through periodic evaluation.

CHAPTER SIX

CONCLUSIONS

This synthesis summarizes the current state-of-the-practice and state-of-the-art utilization of technologies for efficient and effective collection and maintenance of data for highway safety analysis. Previous research reports have suggested technologies as providing a means by which to overcome many of the limitations surrounding safety data. This synthesis documents a number of successful implementations of technologies, whereby these six measures of safety data, timeliness, accuracy, completeness, comprehensiveness, efficiency, and integration, were improved.

A multifaceted approach was used to define safety data requirements and identify technological solutions that enhance the timeliness, accuracy, efficiency, completeness, comprehensiveness, and integration of safety data sources. Six specific tasks were undertaken:

- New safety analysis tools to identify data requirements were examined.
- A survey of states was implemented to determine compliance with identified data requirements (crash, roadway inventory, and traffic operations) and to discover types of technologies used to collect, process, and manage the three types of data, as well as the extent of their use.
- To ascertain additional information or clarify information on technology use, follow-up with the states was undertaken.
- A matrix of available technologies to support collection, processing, and maintenance within the three primary data categories was developed.
- A literature search on technologies identified from the survey, general knowledge of the area, and through suggestions from the research review panel was completed.
- A matrix matching technologies to specific data requirements to guide agencies seeking to employ new technologies to support safety information systems was developed.

A comprehensive listing of safety data elements necessary for the use of the new safety analysis tools, Interactive Highway Safety Design Model (IHSDM) and SafetyAnalyst, was included in Appendix A of the report. The list is extensive and promises of new additions to the software packages will most likely lengthen the list in the coming months. Special attention was given to the differences in data requirements between IHSDM and SafetyAnalyst. IHSDM requires very detailed geometric data files for a specific section of roadway, whereas SafetyAnalyst requires comprehensive crash and road inventory data for a wide area or state. These differences leave little room for overlap in data requirements.

Federally mandated data programs such as those for bridge structures, railroad crossings, and the Highway Performance Monitoring System have a strong effect on a state's comprehensive collection of data. For bridge and pavement data elements, all states reported collecting these data elements comprehensively. For elements such as road geometric elements (horizontal and vertical curvature), however, fewer than half of the responding states indicated collecting the data elements comprehensively—most collect samples or on an as-needed basis, if at all. Overall, a number of data elements required by safety programs (i.e., cross-slope, barriers, and intersection elements) are also underreported.

The survey of states indicated that the use of technologies for collecting crash data was limited, and so too were efforts to research new methods for crash data collection and maintenance. Although a number of states mentioned the capture of electronic crash reports, few had widespread use throughout the state. A number of technologies exist within these electronic reporting systems (i.e., barcode scanners, global positioning system location devices, etc); however, these too are not used extensively. Some states noted that other technologies (i.e., laser or survey grade measurement and digital photography) are used for special studies, but that much of the data is filed away in hard copy limiting its long-term usefulness.

As noted both in the crash database and road inventory surveys, route-milepost is the most common linear referencing system in use by state departments of transportation DOTs. Unfortunately, the route-milepost system does not easily allow for multiple years of historical road inventory data to be readily available for analysis, making linkage to historical crash records difficult. Furthermore, roadway inventory databases were reported as dynamic databases that are constantly changing. These dynamic systems make it difficult to manage change dates for specific pieces of information (e.g., the date that raised pavement markers were added to a section of roadway or the date when a traffic signal was added to an intersection). Most states archive the road inventory database each year, but not all roads are updated annually. Therefore, it is hard to establish a link between road characteristic changes and safety improvements without chasing a significant paper trail of contract documents.

According to the road inventory survey, technologies were used sparingly except for pavement management and video-log. Where federal programs require more comprehensive data, states have adopted technologies to increase their efficiency with these data collection activities. However, many of the data elements are still collected manually with pen and paper or pulled from plan and profile sheets. Expansion of this type of data collection system would be cost-prohibitive. Additionally, much of the data collected in hard-copy format must be entered or scanned, resulting in additional labor costs.

The availability of AASHTOWare products for data management for federal requirements is viewed as a benefit to the states. These software packages are typically designed to be flexible for use in most states, while allowing nationwide analysis of exported data. Further development of the anticipated Transportation Safety Information Management System, although daunting, is expected to be an important venture.

The states had great difficulty in responding to the traffic operations data survey. However, it is clear that additional efforts to define a more comprehensive system for traffic operations data collection and maintenance are needed. Several states indicated that multiple databases were maintained to house traffic operations data—some for Intelligent Transportation System data archives, some for traffic signal data, and others to support volume requirements for the Highway Performance Monitoring System. One of the overarching requirements of both IHSDM and SafetyAnalyst is the need for volume data. More integrated and effective data systems will be needed to meet these demands.

Although several states mentioned plans for deployment of portable nonintrusive traffic detection systems in the near future (5–10 years), few states have been early adopters. The use of portable nonintrusive technologies will be required to expand the traffic data needs of future safety analysis programs.

Many technologies exist that can provide numerous efficiencies in safety data acquisition, processing, and management. Unfortunately, many of these technologies are not being fully or even partially integrated into the safety data process. This document focused on the review of technologies that had been used successfully in one or more states. Often, specific evaluations of the technology implementations were not completed; however, it could be assumed that the technologies had produced noticeable benefits.

There are key inexpensive technologies such as global positioning systems and geographic information systems that are critical to data collection and maintenance for almost all databases (crash, roadway inventory, and traffic operations) that have not been fully capitalized on. Most states do maintain a geographic information system; however, they incorporate only a small portion of the data that they collect. Furthermore, outdated procedures of locating crash locations in a post hoc manner using the police-reported description and route-milepost data are unnecessary and time-consuming. However, without support of management and significant investment in the technologies, little improvement in updating processes for safety data is likely to occur.

The choices regarding linear referencing systems and the use of dynamic versus static road characteristics databases have dramatic effects on a states' ability to use data systems for safety analysis. Some are much better than others, yet some choices have positive implications for one database and negative implications for others. These choices are difficult and must be consciously considered upfront in the design and implementation of a safety data system. Unfortunately, most of the data sets that are currently being used for safety data analysis were developed for purposes other than safety and as such do not support safety analysis effectively. The lack of federally mandated safety data programs in past years has hindered this integration.

Advances in wireless communications and mobile computing allow for ease of mobile data capture and reporting; however, paper and pen remains a top medium for crash data collection. In a time when it is possible to send a package across the country in less than 24 h and receive immediate e-mail confirmation of delivery with an attached digital signature, it is feasible to upgrade and expedite our crash records systems. Several states have begun to deploy business-like systems for the capture and delivery of this critical safety data. Not only are these states able to recoup the costs of the data system, but they are also able to recoup costs for damage to infrastructure owing to the timeliness of the data.

Of all of the required data elements, key design elements (horizontal and vertical curvature and grade) are missing from road inventory databases. There is no doubt that some of these elements have strong ties to crash occurrence; however, serious attention must be given to the requirements of comprehensive collection and accuracy of any such data. Several commercial pavement profiling and video-log systems provide road design data, but the accuracy of the data is not clear. A recent development by FHWA, the Digital Highway Measurement Vehicle, provides extremely accurate and comprehensive road design data. Streamlining this system or a similar system and deploying it in a widespread fashion will be necessary to meet the needs of safety analysis in the near future.

Finally, several exceptions should be noted with regard to technology implementation:

- Technology alone cannot solve all of the problems associated with safety data systems, especially those

related to inadequate institutional cooperation. Organizational issues should be addressed before considering technological advancements.
- Technology implementation and maintenance can be capital-intensive, requiring significant funding and programmatic support—therefore, the benefits and costs must be clearly evident across all affected agencies.
- Technologies are constantly evolving; therefore, agencies should seek to employ technologies that allow for flexibility. Additionally, a practical plan for maintaining and upgrading the technologies, as well as assessing their continued effectiveness, should be developed before initial investment and implementation of the technology.
- No single technology will allow for the collection and maintenance of the varied databases required for safety analysis—hence, an array of technologies should be considered.

In conclusion, technology is a means by which to overcome many of the limitations set forth by Pfefer et al. in *NCHRP Report 430*. Given institutional support, cooperative agreements between agencies, and necessary resources positive change can occur in safety data systems.

REFERENCES

1. *Traffic Safety Facts 2003: A Compilation of Motor Vehicle Crash Data from the Fatal Analysis Reporting System and the General Estimates System: Early Edition*, National Center for Statistics and Analysis, National Highway Traffic Safety Administration, Washington, D.C., 2004, 220 pp.
2. "Strategic Highway Safety Plan," American Association of State Highway and Transportation Officials, Washington, D.C., Sep. 1997 [Online]. Available: http://safety.transportation.org/plan.aspx [nd].
3. Vogt, A. and J.G. Bared, "Accident Models for Two-Lane Rural Roads: Segments and Intersections," Federal Highway Administration, Washington, D.C., Oct. 1998, 179 pp.
4. Washington, S., B. Persaud, C. Lyon, and J. Oh, "Validation of Accident Models for Intersections," Federal Highway Administration, Washington, D.C., July 2005, 311 pp.
5. Pfefer, R.C., T.R. Neuman, and R.A. Raub, *NCHRP Report 430: Improved Safety Information to Support Highway Design,* Transportation Research Board, National Research Council, Washington, D.C., 1999, 178 pp.
6. "Traffic Records: A Highway Safety Program Advisory," National Highway Traffic Safety Administration, Washington, D.C., June 1, 2003 [Online]. Available: http://www.nhtsa.dot.gov/people/perform/pdfs/Advisory June12003Version.pdf [accessed June 21, 2005].
7. Crow, M., et al. *Traffic Safety Information Systems in Europe and Australia*, Report FHWA-PL-04-010, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., Oct. 2004, 112 pp.
8. Pfefer, R.C., R.A. Raub, and R.E. Lucke, *Highway Safety Data: Costs, Quality, and Strategies for Improvement, Final Report*, Report FHWA-RD-96-192, Federal Highway Administration, McLean, Va., Jan. 1998, 95 pp.
9. Depue, L., *NCHRP Synthesis of Highway Practice 322: Safety Management Systems*, Transportation Research Board, National Research Council, Washington, D.C., 2003, 42 pp.
10. Bahar, G., M. Masliah, C. Mollett, and B. Persaud, *NCHRP Report 501: Integrated Management Process to Reduce Highway Injuries and Fatalities Statewide*, Transportation Research Board, National Research Council, Washington, D.C., 2003, 158 pp.
11. Council, F. and D. Harkey, *Traffic Safety Information Systems International Scan: Strategy Implementation,* White Paper, Report FHWA-HRT-06-099, Federal Highway Administration, Washington, D.C., 2006, 64 pp.
12. Intermodal Surface Transportation Efficiency Act of 1991, Bureau of Transportation Statistics, Washington, D.C. [Online]. Available: http://www.bts.gov/laws_and_regulations/docs/istea1.htm [accessed June 15, 2005].
13. Depue, L., Safety Management System Update Survey, Central Missouri State University, Warrensburg, 2001, unpublished.
14. *A National Agenda for the Improvement of Highway Safety Information Systems*, National Safety Council, Chicago, Ill., 1996, 10 pp.
15. O'Day, J., *NCHRP Synthesis of Highway Practice 192: Accident Data Quality*, Transportation Research Board, National Research Council, Washington, D.C., 1993, 48 pp.
16. Hughes, W., et al., *New and Emerging Technologies for Improving Accident Data Collection*, Report FHWA-RD-92-097, Federal Highway Administration, Washington, D.C., 1993.
17. "National Model: Statewide Application of Data Collection & Management Technology to Improve Highway Safety—TraCS, Traffic, and Criminal Software," Motor Vehicle Division, Iowa Department of Transportation, Ames, Aug. 19, 2003 [Online]. Available: http://www.dot.state.ia.us/natmodel/tracs.htm [accessed July 29, 2005].
18. "National Model Project Report II: Electronic Data Quality Benefits," Vol. 2a, Federal Highway Administration, Washington, D.C., Apr. 2002 [Online]. Available: http://www.dot.state.ia.us/natmodel [accessed Oct. 28, 2005].
19. Hu, P., B. Boundy, T. Truett, E. Chang, and S. Gordon, *Cross-Cutting Studies and State-of-the-Practice Reviews: Archive and Use of ITS-Generated Data*, ORNL/TM-2002/120, Center for Transportation Analysis, Oak Ridge National Lab, Oak Ridge, Tenn., Apr. 2002, 194 pp.
20. McDonald, M., Association of Transportation Safety Information Professionals Application for Best Practices Recognition 2004: Delaware Automated Crash Reporting System [Online]. Available: http://www.atsip.org/oldsite/forum2004/best_practices/Delaware_Automated_Crash_Reporting.pdf [accessed Oct. 28, 2005].
21. Casper, L., Association of Transportation Safety Information Professionals Application for Best Practices Recognition 2005: New York TraCS Project [Online]. Available: http://www.atsip.org/images/uploads/New_York_TraCS_Best_Practices_Application.doc [accessed Oct. 28, 2005].
22. *Products: Traffic Collision Database*, Crossroads Software, Inc., Brea, Calif. [Online]. Available: http://www.crossroadssoftware.com/products/traffic/tcdframes.htm [accessed July 30, 2005].
23. "Products: Handheld Citation and Reporting Writing Program," Crossroads Software, Inc., Brea, Calif. [Online]. Available: http://www.crossroadssoftware.com/products/handheld/handheld_program.htm [accessed July 30, 2005].
24. Alewelt, B., Association of Transportation Safety Information Professionals: Application for Best Practices Recognition 2004, *Mobile Capture & Reporting System* [Online]. Available: www.atsip.org/oldsite/forum2004/best_practices/Illinois_mobilecapturereporting. pdf [accessed July 31, 2005].

25. Sarasua, W., J. Ogle, and A. Dunning, *GIS-Based Analysis of Rural Crashes in South Carolina*, Report xx, South Carolina State University Transportation Center, Orangeburg, exp. July 2006.
26. Green, E. and K. Agent, "Evaluation of the Accuracy of GPS as a Method of Locating Traffic Collisions," Kentucky Transportation Center, Lexington, 2004 [Online]. Available: http://www.ktc.uky.edu/Reports/KTC_04_08_SPR_276_04_1F.pdf.
27. McKnight, A.S., C.W. Mosher, and D.J. Bozak, "Evaluation of Emerging Technologies for Traffic Crash Reporting," Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 1998, 96 pp. [Online]. Available: http://ntl.bts.gov/lib/000/700/766/695.pdf.
28. Hughes, R. and M. Stanard, "North Carolina's Experimental Use of GPS to Provide an 'Integrated' GIS Analysis for Truck Involved Crash and Commercial Vehicle Enforcement Activity," *Crime Mapping News*, Vol. 6, No. 2, Spring 2004.
29. Miller, G., "The Magical Number Seven Plus or Minus Two: Some Limits on Our Capacity for Processing Information," *Psychological Review*, Vol. 63, 1956, pp. 81–97.
30. Thibodeau, P., "Bush Plan Supports States in Developing Driver's License Standards," *Computerworld*, July 16, 2002, p. 3 [Online]. Available: http://www.computerworld.com/securitytopics/security/story/0,10801,72760,00.html?from=story_picks.
31. Ramasastry, A., "Why the 'Real ID' Act Is a Real Mess," *CNN.com*, Law Section, Aug. 12, 2005, pp. 1–2.
32. Nelson, L., "Is That You? Prove It! Getting a Counterfeit Driver's License Is Getting Tougher," *Advanced Imaging*, Vol. 20, Mar. 2005, pp. 46–49.
33. Woodward, K., "Chip-Based Driver's Licenses Move Forward, But in the Slow Lane," *Card Technologies*, Vol. 10, Oct. 2005, p. 30.
34. Parker, G., "Florida Driver's License Used as Model," *Tampa Tribune*, Aug. 2, 2005, p. 14.
35. Chabrow, E. and L. Greenemeier, "'Real ID' Faces Reality," *Informationweek*, May 16, 2005, p. 22.
36. Fonda, A.G., "The (Un)Reliability of Scene Measurement and Accident Reconstruction," *Accident Reconstruction Newsletter*, Vol. 5, No. 4, Apr. 2003 [Online]. Available: http://www.accidentreconstruction.com/newsletter/apr03/fonda.asp.
37. Behring, D., J. Thesing, H. Becker, and R. Zobel, "Optical Coordinate Measuring Techniques for the Determination and Visualization of 3D Displacements in Crash Investigations," Society of Automotive Engineers, Inc., Washington, D.C., 2001.
38. Galvin, B., "Portable Crash Scene Mapping Tools Prove Quick, Accurate, Economical," *Accident Reconstruction Newsletter*, Vol. 7, No. 9, Sep. 2005.
39. Rentschler, W. and V. Uffenkamp, "Digital Photogrammetry in Analysis of Crash Tests," *SAE Special Publications*, Society of Automotive Engineers, Inc., Washington, D.C., 1999, pp. 31–41.
40. Galvin, B., "Detailed, Accurate Diagram Worth a Thousand Words in Court," *Accident Reconstruction Newsletter*, Apr. 2003, Vol. 5, No. 4 [Online]. Available: http://www.accidentreconstruction.com/newsletter/apr03/cad.asp.
41. "Event Data Recorder Applications for Highway and Traffic Safety: Event Data Recorder Research History" [Online]. Available: http://www-nrd.nhtsa.dot.gov/edr-site/history.html [accessed Nov. 7, 2005].
42. *Event Data Recorders, Summary of Findings by the NHTSA Working Group*, Final Report, National Highway Traffic Safety Administration, Washington, D.C., Apr. 2001.
43. "Safety: During: Protecting Occupants: Event Data Recorders: Frequently Asked Questions," General Motors Corporation, Detroit, Mich. [Online]. Available: http://www.gm.com/company/gmability/safety/protect_occupants/event_data_recorders/index.html [accessed Nov. 7, 2005].
44. Gabler, H.C., D.J. Gabauer, H.L. Newell, and M.E. O'Neill, *Web Document 75: Use of Event Data Recorder (EDR) Technology for Highway Crash Data Analysis*, Transportation Research Board, National Research Council, Washington, D.C., 2004, 210 pp.
45. Kowalick, T., "World's First Motor Vehicle 'Black Box' Standard," Press Release, IEEE, Piscataway, N.J., 2004.
46. Harkey, D.L., C. Yi, and J. Feaganes, "Evaluation and Validation of an Automated In-Vehicle Data Collection System for Developing Roadway Alignments: Final Report," Contract No. DTFH61-00-C-00034, Highway Safety Information System IV, Highway Safety Research Center, University of North Carolina, Chapel Hill, Aug. 2003.
47. Gluck, J., H.S. Levinson, and V. Stover, *NCHRP Report 420: Impacts of Access Management Techniques*, Transportation Research Board, National Research Council, Washington, D.C., 1999, 163 pp.
48. Souleyrette, R., S. Veeramallu, and S. Hallmark, "Use of Remote Sensing to Identify Access Elements for Safety Analysis," Center for Transportation Research and Education, Iowa State University, Ames, May 2001 [Online]. Available: http://www.ctre.iastate.edu/reports/RemoteSenseAccess.pdf [accessed Oct. 28, 2005].
49. AASHTOWare [Online]. Available: http://www.aashtoware.org/?siteid=28&pageid=73 [accessed Nov. 7, 2005].
50. Dixon, K. and J. Ogle, *Road Life History Database Feasibility Study: Final Report*, Georgia Department of Transportation, Atlanta, Oct. 2004.
51. *Field Test of Monitoring of Urban Vehicle Operations Using Non-Intrusive Technologies*, Report FHWA-PL-97-018, Federal Highway Administration, Washington, D.C. [Online]. Available: http://www.dot.state.mn.us/guidestar/nitfinal/execsum.htm [accessed Nov. 7, 2006].
52. Skszek, S.L., "*State-of-the-Art" Report on Non-Traditional Traffic Counting Methods*, Final Report 503, Arizona Department of Transportation, Tucson, Oct. 2001.

53. Slack, B., "Traffic Counts and Traffic Surveys," Aug. 10, 2005 [Online]. Available: http://people.hofstra.edu/geo trans/eng/ch9en/meth9en/ch9m2en.html [Oct. 12, 2005].
54. "Intelligent Transportation Systems—Traffic Surveillance," California Center for Innovative Transportation at the University of California at Berkeley and Caltrans, 2005 [Online]. Available: http://www.calccit.org/itsdeci sion/serv_and_tech/traffic_surveillance/road-based/road side/other_roadside_sum.html [Nov. 24, 2005].
55. *Tracking the Deployment of the Integrated Metropolitan Intelligent Transportation Systems Infrastructure in the USA: FY2002 Results*, ITS Joint Program Office, Federal Highway Administration, Washington, D.C., Apr. 2004.
56. *Metropolitan Intelligent Transportation Systems* (*ITS*) *2002 Deployment Tracking Survey: Final Results—Safety*, ITS Joint Program Office, Federal Highway Administration, Washington, D.C., 2004.
57. McGurrin, M., "What Have We Learned About Intelligent Transportation Systems? Chapter 7: What Have We Learned About Cross-Cutting Technical and Programmatic Issues?" 2000 [Online]. Available: http://www.itsdocs.fhwa.dot.gov/jpodocs/EDLBrow/@@301!.pdf [accessed Nov. 7, 2005].
58. Ogle, J., R. Guensler, and V. Elango, "Georgia's Commute Atlanta Value Pricing Program: Recruitment Methods and Travel Diary Response Rates," *Transportation Research Record 1931*, Transportation Research Board, National Research Council, Washington, D.C., 2005, pp. 28–37.
59. "To Scan or Not to Scan: That Is the Question!" *Micrographics Quarterly*, Colorado State Archives Publication, Vol. 1, No. 2, Winter 2000 [Online]. Available: http://www.colorado.gov/dpa/doit/archives/micrographics_qua rterly/mqw00.htm [accessed Nov. 7, 2005].
60. Webb, S., "Imaging Success Is No Accident, Integrated Solutions," Feb. 2005 [Online]. Available: http://www.integratedsolutionsmag.com/Articles/2005_02/050202.htm [accessed Nov. 7, 2005].
61. National Archives, Washington, D.C. [Online]. Available: http://www.archives.gov/records-mgmt/ [accessed Nov. 7, 2005].
62. Electronic Imaging Guidelines, State Records Administrator, State of Nebraska, Mar. 2003 [Online]. Available: http://www.sos.state.ne.us/admin/record_manage/pdf/gui deline_imaging_march_2003.pdf [accessed Nov. 7, 2005].
63. Capital Wireless Integrated Network, Greenbelt, Md. [Online]. Available: http://www.capwin.org [accessed Oct. 28, 2005].
64. *GIS-Based Crash Referencing and Analysis System*, HSIS Summary Report, FHWA 99-081, Federal Highway Administration, Washington, D.C., Feb. 1999.
65. Smith, R., D. Harkey, and B. Harris, *Implementation of GIS-Based Highway Safety Analysis: Bridging the Gap*, Report FHWA-RD-01-039, Federal Highway Administration, Washington, D.C., 2001 [Online]. Available: www.tfhrc.gov/safety/1039.htm [accessed Oct. 28, 2005].
66. Tsai, Y., M. Wu, and Z.Wang, "Reengineering Roadway Transportation Data Inventory Using GPS/GIS," Applications of Advanced Technologies in Transportation Engineering, Proceedings of the 8th International Conference, May 26–28, 2004, Beijing, China.
67. "A Project Proposal for the Development of a Transportation Safety Information Management System," July 15, 1999 [Online]. Available: http://72.14.207.104/search?q=cache:LB8byjf2TycJ:www.tsass.com/tsims/pdf_doc/TSIMS_Solicitation.pdf+aashtoware+safety+eff iciency&hl=en&ie=UTF-8 [accessed Oct. 13, 2005].
68. "AASHTO—AASHTOWare," *TSIMS News*, Vol. 1, No. 2, Aug. 22, 2003 [Online]. Available: http://www.aashto.org/aashtoware/downloads/downloads.nsf/02156 20f11306ae9862568ce0064971f/69fbb84ad857bd3085 256d8a006d2204/$FILE/TSIMS_August_Newsletter-Final.pdf#search='aashto%20tsims [accessed Oct. 13, 2005].
69. "AASHTO—AASHTOWare—What's New! TSIMS Phase 2 Project—Rescoped" [Online]. Available: http://www.aashtoware.org/?siteid=28&pageid-580 [accessed Oct. 13, 2005].
70. Georgia DOT Transportation Explorer [Online]. Available: http://gdot-web1.dot.state.ga.us/trex/viewer.htm [accessed Nov. 21, 2005].
71. "Intergraph Web Site, Case Study: Oklahoma GRIPs 13 Disparate Databases" [Online]. Available: http://www.intergraph.com/resource_files/case_studies/CS129/CS1 29_print.pdf [accessed Nov. 21, 2005].
72. "Intergraph Web Site, Case Study: Intergraph Helps South Carolina DOT Weather Hurricane Season" [Online]. Available: http://www.intergraph.com/resource_files/case_studies/CS171/CS171_print.pdf [accessed Nov. 21, 2005].
73. Risch, L.R., "AASHTOware Joint Development Process," *Journal of Computing in Civil Engineering*, Vol. 12, No. 1, Jan. 1998, p. 8.
74. AASHTOWare [Online]. Available: http://www.aashto ware.org/?siteid=28 [accessed Oct. 13, 2005].
75. Chaparral Systems Corporation, TRADAS 3 Operations, Santa Fe, N.M., 2004 [Online]. Available: http://www.chapsys.com/tradasoperations.html [accessed July 31, 2005].
76. Borins, S., "The Challenge of Innovating in Government," Innovation in Management Series, PriceWaterhouseCoopers Endowment for the Business of Government, Feb. 2001.
77. Meyer, M., Transportation Innovation and Policy Analysis Course Notes, Georgia Institute of Technology, Atlanta, Jan. 2002.

APPENDIX A

Required Data Elements

Data Category/Type	Data Element	Sub-Element	Data Requirements	
			IHSDM	SafetyAnalyst
Road Inventory (Geometric) Data				
General	Segment	Number		x
		Length		x
		Location		x
	Route	Type		x
		Name or number		x
	Highway system code			x
	County number			x
	District number			o
	City/town number			o
	Jurisdiction			o
	Area type			x
	Date opened to traffic			o
Horizontal Alignment	Horizontal tangent	Heading	x	
		Length	x	
	Horizontal simple curve	Radius	x	
		Position	x	
	Horizontal spiral curve	Presence	x	
		Position	x	
	Horizontal deflection	Angle	x	
		Direction	x	
Vertical Alignment	Vertical point of intersection	Back grade	x	
		Back length	x	
		Forward length	x	
	Vertical tangent	Position	x	
		Length	x	
	Vertical curve	Position	x	
		Length	x	
	Elevations		x	
Cross-section	Thru lanes	Number (dir)		x
		Width		o
	Median	Type		x
		Width		o
	Shoulder	Type	x	x
		Width	x	o
		Slope	x	
		Rounding	x	
	Highway cross slope	Normal crown	x	
		Superelevation	x	
	Pavement type		x	
Lane	Thru lane	Number	x	
		Width	x	
	Auxiliary lane	Number		o
		Passing	x	
		Turning	x	
		Two-way left turn	x	
		Climbing	x	
	Lane offset		x	
	Curve widening		x	

Data Category/Type	Data Element	Sub-Element	Data Requirements	
			IHSDM	SafetyAnalyst
Road Inventory (Geometric) Data				
Roadside	Bike facilities present		x	x
	Driveway density		x	o
	Foreslope	Slope	x	
		Width	x	
	Backslope	Slope	x	
		Width	x	
	Ditch	Bottom shape	x	
		Width	x	
	Obstruction	Offset	x	
		Presence	x	
		Side	x	
	Roadside hazard rating		x	
Intersection	Number of intersection legs		x	
	Approach type (major/minor)		x	
	Intersection skew angle		x	
	Number quadrants w/ limited sight distance		x	
	Intersection location			x
	Type of intersection			x
	Type of traffic control		x	x
	Major road direction			x
	Influence zone	Beginning		x
		End		x
	Offset intersection	Presence		x
		Distance		x
Intersection Leg	Direction			x
	Number of lanes	Through		x
		Right turn	x	x
		Left turn	x	x
	Median type			x
	Signal left-turn phasing			x
	Turn prohibitions			x
Ramps	Ramp	Number		x
		Location		x
		Type		x
		Configuration		x
	Type of connection	At freeway		x
		At crossroad		x
	Number of lanes			x
	Volume — ADT			x

Data Category/Type	Data Element	Sub-Element	Data Requirements	
			IHSDM	SafetyAnalyst
Traffic Operations Data				
Traffic Operations	Terrain		x	o
	Functional classification	Level 1	x	x
		Level 2		o
		Level 3		o
	Speed	Design	x	
		85th	x	
		Posted	x	o
	Volume	ADT	x	x
		DHV	x	o
		Peak hour	x	o
		Growth factor		o
		% heavy vehicles		o
	Access control			o
	Traffic-way flow			x
	Interchange influence area			o

Data Category/Type	Data Element	Sub-Element	Data Requirements		Conformity
			IHSDM	SafetyAnalyst	MMUCC
Crash Data					
Accident-level	Accident case identifier			x	M
	Route type			x	
	Route name/number			x	
	County number			x	M
	Accident location		x	x	S
	Location identifier system			x	
	District number			o	
	City/town number			o	M
	Accident date	Year	x		
		Year, month, day		x	S
	Accident time			x	S
	Relationship to junction		x	x	S
	Driveway indicator			o	
	Light condition			o	M
	Weather condition			o	M
	Roadway surface condition			o	M
	Accident type and manner of collision			x	S
	Contributing circumstances	Environment		o	M
		Road		o	M
	School bus related			x	M
	Work zone related			x	S
	Number of vehicles involved			x	M
	Accident severity		x	x	M
	Alcohol/drug involvement			o	M
	Tow-away indicator			o	
	Run-off road indicator			o	
	Pedestrian indicator			o	
	Bicycle indicator			o	
	Divided highway flag			o	
	Day of week			x	M
Vehicle-level	Initial direction of travel			x	M
	Vehicle maneuver/action			x	M
	Vehicle configuration			x	M
	First harmful event			x	M
Person-level	Driver age			x	S

Notes:
Under SafetyAnalyst: x = mandatory element, o = optional but desired element.
Under MMUCC: M = meets MMUCC guidelines, S = similar to MMUCC guidelines.

APPENDIX B

Survey Respondents

Crash Survey

Arizona
Arkansas
California
Connecticut
Delaware
Georgia
Illinois
Iowa
Maryland
Michigan
Missouri
Nevada
New Hampshire
North Dakota
Ohio
Oklahoma
Oregon
Pennsylvania
Texas
Utah
Washington
West Virginia
Wisconsin
Wyoming

Road Inventory Survey

Arkansas
Colorado
Florida
Georgia
Hawaii
Idaho
Illinois
Iowa
Massachusetts
Minnesota
Mississippi
Missouri
Oklahoma
Oregon
South Carolina
South Dakota
Tennessee
Texas
Washington
Wisconsin

Traffic Operations Survey

Colorado
Connecticut
Florida
Georgia
Illinois
Iowa
Massachusetts
Minnesota
Missouri
Oregon
South Dakota
Tennessee
Texas
Washington
Wisconsin

APPENDIX C

Crash Survey Form

National Cooperative Highway Research Program

Project 20-5, Topic 36-03

QUESTIONNAIRE

New Technologies for Improving Safety Data

We need your assistance in supplying some information about the current status of technology use related to acquisition, processing, and maintenance of road inventory and traffic operations data in your state. The questionnaires should be completed by persons familiar with your states' data activities both at the state and local level.

Over the past few years, the U.S.DOT's focus on safety has led to the development of several new safety analysis tools including the Interactive Highway Safety Design Model (IHSDM), SafetyAnalyst, and *Highway Safety Manual* (*HSM*). These tools have generated new requirements for safety data that stretch far beyond those of the past. The safety analysis tools require accurate and timely crash characteristics including severity and crash location; road inventory characteristics including functional class, number of lanes, shoulder type, markings, lane width, and traffic control; and traffic characteristics including volumes, classification, speeds, and variance by time of day and season. Additionally, data from Emergency Medical Services (EMS), medical records, driver history records, vehicle registration files, citations systems, and incident management systems are also used to support safety analysis.

Given this new set of data requirements, there is a need to improve the efficient data collection, processing, and evaluation required for successful safety programs at the state and municipal levels. This questionnaire seeks to collect information on the state-of-the-practice utilization of technologies for efficient and effective collection and maintenance of data for transportation safety analysis. Specifically, it requests input on types of technologies, software applications, and innovative methods used by different agencies whose data are important for safety analysis. For each technology, information is sought regarding the implementation status, outcomes of evaluations, and efficiencies achieved from use of the technology. Comments and information on new developments and technology needs are also requested.

Please return the completed survey by e-mail, mail, or fax by June 29, 2005, using the contact information below.

E-mail: ogle@clemson.edu
Mail: Jennifer Ogle, Clemson University, Department of Civil Engineering, 208 Lowry Hall, Clemson, SC 29634-0911
Fax: 864-656-2670

National Cooperative Highway Research Program

Project 20-5, Topic 36-03

New Technologies for Improving Safety Data

CRASH RECORDS DATABASE SURVEY

1. Contact information for the person completing this survey.
   a. Name: ______________________________
   b. Title: ______________________________
   c. Agency: ______________________________
   d. Address: ______________________________
   ____
   ____
   e. Telephone: ______________________________
   f. Fax: ______________________________
   g. E-mail: ______________________________

2. Is your agency/division/office represented/active in any of the following safety initiatives at the state or local level? (Please mark all that apply.)

   ☐ Safety management system
   ☐ Traffic records coordinating committee
   ☐ Other safety-related program, please specify: ______________________________

3. Which of the following tasks related to the crash records database does your agency/division/office participate in? (Please mark all that apply.)

   ☐ Data collection
   ☐ Data processing, keying, or other data entry task
   ☐ Database management
   ☐ Data analysis or data user

4. Are the data collected at the local, jurisdictional, or state level?

   ☐ Local
   ☐ Jurisdictional/district
   ☐ State

5. Who maintains the data?

   ☐ Local repository
   ☐ Jurisdictional/district repository
   ☐ State repository

   a. If data are maintained at the local or jurisdictional repositories, are data shared with a central database?

      ☐ Yes
      ☐ No

   b. If yes, how often are data transferred to the central database?

      ☐ Daily
      ☐ Weekly
      ☐ Monthly
      ☐ Quarterly
      ☐ Yearly
      ☐ As needed or other, please specify: ______________________________

c. If no, what are the barriers? ____________________

d. What type of database is used for the central repository?

- ☐ Oracle
- ☐ SQL Server
- ☐ DB2
- ☐ Other, please specify: ____________________

e. Are data transferred electronically to the central repository or submitted in hard-copy format and keyed/entered/held at the central location? (Mark all that apply.)

- ☐ Electronic data transmission
- ☐ Hard-copy submission
- ☐ Other, please specify: ____________________

   i. If data are submitted in hard-copy format, is the original form maintained or scanned to microfilm or digital image file?

   - ☐ Original maintained
   - ☐ Original scanned to microfilm
   - ☐ Original scanned to digital image file

f. Are there manual or automated checks when entering information into databases to ensure quality?

- ☐ Yes
- ☐ No

6. Who has access to the data? (Mark all that apply.)

- ☐ Internal offices
- ☐ Other state agencies
- ☐ Local agencies
- ☐ Public/private sector

7. How is access to the crash record database provided? (Mark all that apply.)

- ☐ Secure intranet site
- ☐ Secure Internet site
- ☐ Unsecured Internet site
- ☐ FTP transfer
- ☐ CD-ROM/DVD
- ☐ Other, please specify: ____________________

a. If external access is granted, do external users have access to the most current data or are data released at intervals (monthly, quarterly, yearly)?

- ☐ Current
- ☐ Interval releases
   - ☐ Monthly
   - ☐ Quarterly
   - ☐ Yearly
   - ☐ Other, please specify: ____________________

8. How current is the information in the database?

- ☐ <1 week old
- ☐ 1–3 months old
- ☐ 3–6 months old
- ☐ 6–12 months old
- ☐ 1–2 years old
- ☐ 2–5 years old
- ☐ Other, please specify: ____________________

9. How many years of data are maintained in the crash records database? ________

10. What year was the database established? ________

11. Does the crash records database contain specific data elements that allow linkage to other databases?

- ☐ Yes
- ☐ No

a. If yes, to which of the following databases can the crash records database be linked? (Mark all that apply.)

- ☐ Crash records
- ☐ EMS run records
- ☐ Medical records/hospital discharge
- ☐ Driver history records
- ☐ Roadway inventory databases
- ☐ Traffic flow databases
- ☐ GIS databases
- ☐ Citation/conviction files
- ☐ Driver's license records
- ☐ Vehicle registration records
- ☐ Commercial motor vehicle registration databases
- ☐ Other, please specify: ____

b. If no, what are the primary challenges or obstacles to data linkage?

____
____
____

12. Is there a website that contains information or data from the crash records database (summary reports, statistics, data dictionary, etc.) or that allows online queries of data?

http:// ____

13. Has your agency conducted, funded, or participated in research regarding data collection and management methods? If so, are there any final reports or other information available?______________________________
____
____

14. Which of the following technologies are used to collect crash reports in your state? (Mark all that apply.)

- ☐ Paper-based form
- ☐ Electronic form (in conjunction with laptop/PDA/computer)
- ☐ Event data recorder ('blackbox' data downloaded from automobile)
- ☐ Other, please specify: ____

a. If you use electronic forms for crash record capture, what software do you use?

- ☐ TRACS
- ☐ Other, please specify: ____

b. If crashes are recorded by electronic and paper-based methods, what percentage of crash records is captured in electronic format? ____________

15. How are crash location data collected?

- ☐ Text description—closest cross street
- ☐ Grid coordinates—map system
- ☐ GPS—latitude/longitude coordinates
  - ☐ Handheld GPS receiver
  - ☐ In-vehicle GPS receiver in patrol car
  - ☐ Other, please specify: ____
- ☐ Other, please specify: ____

16. How accurate is the location information? ____________________

17. What types of training are provided to police officers who collect crash record data?
____

18. Do you use any non-technical strategies to collect crash data (e.g., non-sworn crash investigators or specially trained crash investigation teams)? ____________________

19. Do you employ technologies or methods to speed up the process of crash investigation when the crash occurs during heavy traffic?

    ☐ Yes
    ☐ No

    If yes, please specify: ____________________
    ____
    ____

20. For investigations of severe crashes or for special studies, what technologies are used over and above regular crash investigations (e.g., friction factors using accelerometer or survey device to collect crash site measurements)?
____
____

21. Are the data collected for special studies included in the general crash records database?

    ☐ Yes
    ☐ No

    a. If not, are they readily accessible elsewhere? Explain: ____________________
    ____

TECHNOLOGY DETAILS

The previous questions inquired about the types of data, access, and technologies used to collect the data. In the following section, we would like to obtain additional details on specific technologies or innovations used by your agency. If you use any new, advanced, unusual, or different technologies, software applications, or innovative methods to assist in collecting, processing, or maintaining data, please indicate the type of technology, software, or method in the sections below. We would also like to know if the technologies were developed in-house, by a consultant, or purchased off-the-shelf, and whether or not you have completed any evaluations. Please complete the section for each technology, application, or method that you believe might be important for this study. Additional pages can be added if necessary. For instance, if you identified previously that you use GPS for collecting crash location, please provide details for this technology below. Additionally, we are interested in software applications that you use to process or link data, as well as innovative methods such as training or procedures for efficient data collection for faster incident clearance.

Technology, Software Application, or Innovative Method #1

Descriptive title: ____________________

Who developed the technology/software/method?

☐ Developed in-house
☐ Developed by consultant
☐ Purchased off-the-shelf
☐ Other, please specify: ____________________

If developed by a consultant/vendor, please provide consultant/vendor contact information in the space below.

Company name: ______________________________
Company address: ______________________________
____
Company phone: ______________________________
Company fax: ______________________________
Company contact: ______________________________
Contact e-mail: ______________________________
Company website: ______________________________

How long have you been using the technology/software/method?

- ☐ <1 year
- ☐ 1–2 years
- ☐ 2–5 years
- ☐ >5 years

Have you completed any evaluations of the use of the technology/software/method?

- ☐ Yes
- ☐ No
- ☐ Evaluation in progress

If yes, did the technologies prove to be cost-effective or improve efficiencies in data collection, processing, or maintenance?

- ☐ Yes
- ☐ No
- ☐ Inconclusive

Is the technology/software/method used locally or statewide?

- ☐ Locally
- ☐ Statewide

If the technology/software/method is used locally, are there plans for implementing it statewide?

- ☐ Yes
- ☐ No
- ☐ Don’t know

Did you experience any integration issues?

- ☐ Yes
- ☐ No

If yes, please briefly explain the issues and resolution: ______________________________
____

Use the space below to provide any additional comments about this technology, software application, or method:
____
____
____
____

APPENDIX D

Road Inventory Survey Form

National Cooperative Highway Research Program

Project 20-5, Topic 36-03

QUESTIONNAIRE

New Technologies for Improving Safety Data

We need your assistance in supplying some information about the current status of technology use related to acquisition, processing, and maintenance of road inventory and traffic operations data in your state. The questionnaires should be completed by persons familiar with your states' data activities both at the state and local level.

Over the past few years, the U.S.DOT's focus on safety has led to the development of several new safety analysis tools including the Interactive Highway Safety Design Model (IHSDM), SafetyAnalyst, and *Highway Safety Manual* (*HSM*). These tools have generated new requirements for safety data that stretch far beyond those of the past. The safety analysis tools require accurate and timely crash characteristics including severity and crash location; road inventory characteristics including functional class, number of lanes, shoulder type, markings, lane width, and traffic control; and traffic characteristics including volumes, classification, speeds, and variance by time of day and season. Additionally, data from Emergency Medical Services (EMS), medical records, driver history records, vehicle registration files, citations systems, and incident management systems are also used to support safety analysis.

Given this new set of data requirements, there is a need to improve the efficient data collection, processing, and evaluation required for successful safety programs at the state and municipal levels. This questionnaire seeks to collect information on the state-of-the-practice utilization of technologies for efficient and effective collection and maintenance of data for transportation safety analysis. Specifically, it requests input on types of technologies, software applications, and innovative methods used by different agencies whose data are important for safety analysis. For each technology, information is sought regarding the implementation status, outcomes of evaluations, and efficiencies achieved from use of the technology. Comments and information on new developments and technology needs are also requested.

Please return the completed survey by e-mail, mail, or fax by June 29, 2005, using the contact information below.

E-mail: ogle@clemson.edu
Mail: Jennifer Ogle, Clemson University, Department of Civil Engineering, 208 Lowry Hall, Clemson, SC 29634-0911
Fax: 864-656-2670

National Cooperative Highway Research Program

Project 20-5, Topic 36-03

New Technologies for Improving Safety Data

ROAD INVENTORY DATABASE SURVEY

1. Contact information for the person completing this survey.
   a. Name: ______________________________
   b. Title: ______________________________
   c. Agency: ______________________________
   d. Address: ______________________________
   ____
   ____
   e. Telephone: ______________________________
   f. Fax: ______________________________
   g. E-mail: ______________________________

2. Is your agency/division/office represented/active in any of the following safety initiatives at the state or local level? (Please mark all that apply.)

   ☐ Safety management system
   ☐ Traffic records coordinating committee
   ☐ Other safety-related program, please specify: ______________________________

3. Which of the following tasks related to the road inventory database does your agency/division/office participate in? (Please mark all that apply.)

   ☐ Data collection
   ☐ Data processing, keying, or other data entry task
   ☐ Database management
   ☐ Data analysis or data user

4. Who maintains the data?

   ☐ Local repository
   ☐ Jurisdictional/district repository
   ☐ State repository

   a. If data are maintained at the local or jurisdictional repositories, are data shared with a central database?

      ☐ Yes
      ☐ No

   b. If yes, how often are data transferred to the central database?

      ☐ Daily
      ☐ Weekly
      ☐ Monthly
      ☐ Quarterly
      ☐ Yearly
      ☐ As needed or other, please specify: ______________________________

   c. If no, what are the barriers? ______________________________

d. What type of database is used for the central repository?

- ☐ Oracle
- ☐ SQL Server
- ☐ DB2
- ☐ Other, please specify: ____________________

e. Are data transferred electronically to the central repository or submitted in hard-copy format and keyed/entered/held at the central location? (Mark all that apply.)

- ☐ Electronic data transmission
- ☐ Hard-copy submission
- ☐ Other, please specify: ____________________

i. If data are submitted in hard-copy format is the original form maintained or scanned to microfilm or digital image file?

- ☐ Original maintained
- ☐ Original scanned to microfilm
- ☐ Original scanned to digital image file

f. Are there manual or automated checks when entering information into databases to ensure quality?

- ☐ Yes
- ☐ No

5. Who has access to the data? (Mark all that apply.)

- ☐ Internal offices
- ☐ Other state agencies
- ☐ Local agencies
- ☐ Public/private sector

6. How is access to the roadway inventory database provided? (Mark all that apply.)

- ☐ Secure intranet site
- ☐ Secure Internet site
- ☐ Unsecured Internet site
- ☐ FTP transfer
- ☐ CD-ROM/DVD
- ☐ Other, please specify: ____________________

a. If external access is granted, do external users have access to the most current data or are data released at intervals (monthly, quarterly, yearly)?

- ☐ Current
- ☐ Interval releases
  - ☐ Monthly
  - ☐ Quarterly
  - ☐ Yearly
  - ☐ Other, please specify: ____________________

7. How current is the information in the database?

- ☐ <1 week old
- ☐ 1–3 months old
- ☐ 3–6 months old
- ☐ 6–12 months old
- ☐ 1–2 years old
- ☐ 2–5 years old
- ☐ Other, please specify: ____________________

8. How many years of data are maintained in the roadway inventory database? ________

9. What year was the database established? ________

10. Do you archive the data at regular intervals to preserve road history? ____

11. Does the roadway inventory database contain specific data elements that allow linkage to other databases?

- ☐ Yes
- ☐ No

a. If yes, to which of the following databases can the roadway inventory/pavement monitoring database be linked? (Mark all that apply.)

- ☐ Crash records
- ☐ EMS run records
- ☐ Medical records/hospital discharge
- ☐ Driver history records
- ☐ Roadway inventory databases
- ☐ Traffic flow databases
- ☐ GIS databases
- ☐ Citation/conviction files
- ☐ Driver's license records
- ☐ Vehicle registration records
- ☐ Commercial motor vehicle registration databases
- ☐ Other, please specify: ____

b. If no, what are the primary challenges or obstacles to data linkage?
____
____
____

12. Is there a website that contains information or data from the roadway inventory/pavement monitoring database (summary reports, statistics, data dictionary, etc.) or that allows online queries of data?

http:// ____

13. Has your agency conducted, funded, or participated in research regarding data collection and management methods for roadway inventory or pavement monitoring? If so, are there any final reports or other information available?
____
____

14. Who collects the information in your roadway inventory file?

- ☐ Area offices
- ☐ District offices
- ☐ Specialized team
- ☐ Consultants
- ☐ Other, please specify: ____

15. Are these data maintained in paper-based files or computerized files?

- ☐ Paper-based
- ☐ Electronic
- ☐ Other, please specify: ____

16. How often does the state conduct a complete re-inventory of roadway data?

    - ☐ Every year
    - ☐ Every other year
    - ☐ Every three years
    - ☐ Every four years
    - ☐ Every five years
    - ☐ No standard schedule

17. How do you check and/or update the roadway inventory (e.g., updates based on as-built plans or drive-by windshield surveys)? ____
    ____

18. What is the primary linear referencing system for the state database? Is a GIS-based reference system currently in use? Are there any plans to use a GIS- or GPS-based reference system in the near future?
    ____
    ____
    ____

19. Is the roadway inventory coded for use/display in a GIS?

    - ☐ Yes
    - ☐ No

    If yes, what methods do you use for coding?

    - ☐ Segment (from node to node)
    - ☐ Route and milepoint (linear distance reference)
    - ☐ Coordinates (latitude/longitude)
    - ☐ Other, please specify: ____

20. Please note the types of road characteristics you collect/manage for each roadway type using the following convention. You may use multiple letters for each box. Leave the box blank if none of the categories apply.

    a. Categories are:

    C – collect data **c**omprehensively (e.g., roadway inventory)
    S – collect data using **s**ampling (e.g., HPMS)
    A – collect data on an **a**s-needed basis for special studies (e.g., high accident incidence, traffic control device warrant)
    M – **m**anage and disseminate data including data storage
    U – **u**ser of data collected by another organization

Types of Roads							
Road Characteristics Data	**Limited Access**		**Arterials**		**Collectors**		**Local**
Cross-Section Elements							
Number of lanes							
Lane width							
Lane type							
Shoulder width							
Shoulder type							
Edge treatments (SafetyEdge)							
Median width							
Median type							
ROW width							
Cross-slope (normal crown)							
Barriers (type, length)							
Roadway Structure Elements							
Bridges							
Railroad crossings							
Multi-use paths/bike paths							
Pedestrian facilities							
Tunnels							
Geometric Elements							
Grade							
Vertical curvature							
Horizontal curvature							
Superelevation							
Sight distance							
Speed limit							
Sign inventory							
Truck/weight restrictions							
Intersection Elements							
Number of lanes/approach							
Signal timing							
Traffic control							
Pavement Elements							
Pavement material							
Pavement distress data							
Skid resistance							
Ride quality							
Pavement markings							

21. How do you collect geometric elements such as horizontal curvature and vertical grade?

- ☐ Field survey using pen and paper
- ☐ Palm top/notebook computer inventory (without GPS)
- ☐ GPS-based data collection with attributes
- ☐ Manual video logging (post-process extraction done manually)
- ☐ Automated video collection (either real-time or post-process extraction automated)
- ☐ Automated data collection using sensor technology (other than video)
- ☐ Other, please specify: ____________________

If automated data collection using sensor technology, specify what type of technology:

- ☐ ARAN
- ☐ Custom vehicle
- ☐ Other, please specify: ____________________

22. How do you collect cross-section elements such as barriers and clearzone maintenance?

- ☐ Field survey using pen and paper
- ☐ Palm top/notebook computer inventory
- ☐ GPS-based data collection with attributes
- ☐ Video logging
- ☐ Other, please specify: ____________________

23. How do you collect sign inventory elements such as location and type of sign?

- ☐ Field survey using pen and paper
- ☐ Palm top/notebook computer inventory
- ☐ GPS-based data collection with attributes
- ☐ Video logging
- ☐ Other, please specify: ____________________

Is sign retro-reflectivity collected?

- ☐ Yes
- ☐ No

If yes, what technology is used to collect the retro-reflectivity data? ____________________
____

24. How do you collect pavement marking data?

- ☐ Field survey using pen and paper
- ☐ Palm top/notebook computer inventory
- ☐ GPS-based data collection with attributes
- ☐ Video logging
- ☐ Other, please specify: ____________________

Is pavement marking retro-reflectivity collected?

- ☐ Yes
- ☐ No

25. How do you collect pavement distress data?

- ☐ Field survey using pen and paper
- ☐ Palm top/notebook computer inventory (without GPS)
- ☐ GPS-based data collection with attributes
- ☐ Video logging
- ☐ Automated data collection using sensor technology (other than video)
- ☐ Other, please specify: ____________________

If automated data collection using sensor technology, specify what type of technology:

- ☐ ARAN
- ☐ Custom vehicle
- ☐ Other, please specify: ____________________

26. How do you collect pavement skid resistance?

- ☐ Manually using drag-sled
- ☐ Automated data collection using sensor technology (specify test type)
  - ☐ locked-wheel
  - ☐ spin-up
  - ☐ surface texture measurement

27. Do you plan to deploy any new technologies within the next 5–10 years for collecting roadway inventory data?

- ☐ Yes
- ☐ No

If yes, please specify what types of technologies you plan to deploy? ____________________
____
____

28. What are the primary uses for your road characteristics data?

- ☐ Federal reporting
- ☐ Input to safety evaluation
- ☐ Planning
- ☐ Design
- ☐ Other, please specify: ____________________

29. What is the frequency of data collection?

Data Type	Frequency			
	As Needed	Monthly	Yearly	Other, specify:
Cross section				
Roadway structure				
Geometric				
Intersection				
Pavement				

30. Do you collect or tabulate specific truck traffic data [such as weigh in motion (WIM)] and, if so, how and what specific data are collected? ____________________
____

31. What is the extent of GIS usage in your agency?

- ☐ Complete integration of road characteristics and traffic data
- ☐ Limited integration of attributes for specific uses
  - ☐ Planning
  - ☐ Superload vehicle permitting
  - ☐ Pavement management
  - ☐ Safety
  - ☐ Other, please specify: ____________________

Use this space to provide any additional comments or information related to your roadway inventory database or pavement monitoring:

____
____
____

TECHNOLOGY DETAILS

The previous questions inquired about the types of data, access, and technologies used to collect the data. In the following section, we would like to obtain additional details on specific technologies or innovations used by your agency. If you use any new, advanced, unusual, or different technologies, software applications, or innovative methods to assist in collecting, processing, or maintaining data, please indicate the type of technology, software, or method in the sections below. We would also like to know if the technologies were developed in-house, by a consultant, or purchased off-the-shelf, and whether or not you have completed any evaluations. Please complete one section for each technology, software application, or method that you believe might be important for this study. Additional pages can be added if necessary. For instance, if you identified previously that you use an instrumented vehicle for collecting roadway inventory data, please provide details for this technology below. Additionally, we are interested in software applications that you use to process or link data, as well as innovative methods such as training or procedures for efficient data collection.

Technology, Software Application, or Innovative Method #1

Descriptive title: ____

Who developed the technology/software/method?
- ☐ Developed in-house
- ☐ Developed by consultant
- ☐ Purchased off-the-shelf
- ☐ Other, please specify: ______________________________________

If developed by a consultant/vendor, please provide consultant/vendor contact information in the space below.

Company name: ____
Company address: ____
____
Company phone: ____
Company fax: ____
Company contact: ____
Contact e-mail: ____
Company website: ____

How long have you been using the technology/software/method?

- ☐ <1 year
- ☐ 1–2 years
- ☐ 2–5 years
- ☐ >5 years

Have you completed any evaluations of the use of the technology/software/method?

- ☐ Yes
- ☐ No
- ☐ Evaluation in progress

If yes, did the technologies prove to be cost-effective or improve efficiencies in data collection, processing, or maintenance?

- ☐ Yes
- ☐ No
- ☐ Inconclusive

Is the technology/software/method used locally or statewide?

- ☐ Locally
- ☐ Statewide

If the technology/software/method is used locally, are there plans for implementing it statewide?

- ☐ Yes
- ☐ No
- ☐ Don't know

Did you experience any integration issues?

- ☐ Yes
- ☐ No

If yes, please briefly explain the issues and resolution: ____

Use the space below to provide any additional comments about this technology, software application, or method:

____
____
____
____

APPENDIX E

Traffic Operations Survey Form

National Cooperative Highway Research Program

Project 20-5, Topic 36-03

QUESTIONNAIRE

New Technologies for Improving Safety Data

We need your assistance in supplying some information about the current status of technology use related to acquisition, processing, and maintenance of road inventory and traffic operations data in your state. The questionnaires should be completed by persons familiar with your states' data activities both at the state and local level.

Over the past few years, the U.S.DOT's focus on safety has led to the development of several new safety analysis tools including the Interactive Highway Safety Design Model (IHSDM), SafetyAnalyst, and *Highway Safety Manual* (*HSM*). These tools have generated new requirements for safety data that stretch far beyond those of the past. The safety analysis tools require accurate and timely crash characteristics including severity and crash location; road inventory characteristics including functional class, number of lanes, shoulder type, markings, lane width, and traffic control; and traffic characteristics including volumes, classification, speeds, and variance by time of day and season. Additionally, data from Emergency Medical Services (EMS), medical records, driver history records, vehicle registration files, citations systems, and incident management systems are also used to support safety analysis.

Given this new set of data requirements, there is a need to improve the efficient data collection, processing, and evaluation required for successful safety programs at the state and municipal levels. This questionnaire seeks to collect information on the state-of-the-practice utilization of technologies for efficient and effective collection and maintenance of data for transportation safety analysis. Specifically, it requests input on types of technologies, software applications, and innovative methods used by different agencies whose data are important for safety analysis. For each technology, information is sought regarding the implementation status, outcomes of evaluations, and efficiencies achieved from use of the technology. Comments and information on new developments and technology needs are also requested.

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E-mail: ogle@clemson.edu
Mail: Jennifer Ogle, Clemson University, Department of Civil Engineering, 208 Lowry Hall, Clemson, SC 29634-0911
Fax: 864-656-2670

National Cooperative Highway Research Program

Project 20-5, Topic 36-03

New Technologies for Improving Safety Data

TRAFFIC OPERATIONS DATABASE SURVEY

1. Contact information for the person completing this survey.
   a. Name: ____________________
   b. Title: ____________________
   c. Agency: ____________________
   d. Address: ____________________
   ____
   ____
   e. Telephone: ____________________
   f. Fax: ____________________
   g. E-mail: ____________________

2. Is your agency/division/office represented/active in any of the following safety initiatives at the state or local level? (Please mark all that apply.)

   ☐ Safety management system
   ☐ Traffic records coordinating committee
   ☐ Other safety-related program, please specify: ____________________
   ____

3. Which of the following tasks related to the traffic operations database does your agency/division/office participate in? (Please mark all that apply.)

   ☐ Data collection
   ☐ Data processing, keying, or other data entry task
   ☐ Database management
   ☐ Data analysis or data user

4. Who maintains the data?

   ☐ Local repository
   ☐ Jurisdictional/district repository
   ☐ State repository

   a. If data are maintained at the local or jurisdictional repositories are data shared with a central database?

   ☐ Yes
   ☐ No

   b. If yes, how often are data transferred to the central database?

   ☐ Daily
   ☐ Weekly
   ☐ Monthly
   ☐ Quarterly
   ☐ Yearly
   ☐ As needed or other, please specify: ____________________

   c. If no, what are the barriers? ____________________

d. What type of database is used for the central repository?

- ☐ Oracle
- ☐ SQL Server
- ☐ DB2
- ☐ Other, please specify: ______________________________

e. Are data transferred electronically to the central repository or submitted in hard-copy format and keyed/entered/held at the central location? (Mark all that apply.)

- ☐ Electronic data transmission
- ☐ Hard-copy submission
- ☐ Other, please specify: ______________________________

i. If data are submitted in hard-copy format is the original form maintained or scanned to microfilm or digital image file?

- ☐ Original maintained
- ☐ Original scanned to microfilm
- ☐ Original scanned to digital image file

f. Are there manual or automated checks when entering information into databases to ensure quality?

- ☐ Yes
- ☐ No

5. Who has access to the data? (Mark all that apply.)

- ☐ Internal offices
- ☐ Other state agencies
- ☐ Local agencies
- ☐ Public/private sector

6. How is access to the roadway inventory database provided? (Mark all that apply.)

- ☐ Secure intranet site
- ☐ Secure Internet site
- ☐ Unsecured Internet site
- ☐ FTP transfer
- ☐ CD-Rom/DVD
- ☐ Other, please specify: ______________________________

a. If external access is granted, do external users have access to the most current data or are data released at intervals (monthly, quarterly, yearly)?

- ☐ Current
- ☐ Interval releases
  - ☐ Monthly
  - ☐ Quarterly
  - ☐ Yearly
  - ☐ Other, please specify: ______________________________

7. How current is the information in the database?

- ☐ <1 week old
- ☐ 1–3 months old
- ☐ 3–6 months old
- ☐ 6–12 months old
- ☐ 1–2 years old
- ☐ 2–5 years old
- ☐ Other, please specify: ______________________________

8. How many years of data are maintained in the roadway inventory database? _______________

9. What year was the database established? __________

10. Do you archive the data at regular intervals to preserve road history? ______________________________________
____

11. Does the roadway inventory database contain specific data elements that allow linkage to other databases?

    - ☐ Yes
    - ☐ No

    a. If yes, to which of the following databases can the roadway inventory/pavement monitoring database be linked? (Mark all that apply.)

    - ☐ Crash records
    - ☐ EMS run records
    - ☐ Medical records/hospital discharge
    - ☐ Driver history records
    - ☐ Roadway inventory databases
    - ☐ Traffic flow databases
    - ☐ GIS databases
    - ☐ Citation/conviction files
    - ☐ Driver's license records
    - ☐ Vehicle registration records
    - ☐ Commercial motor vehicle registration databases
    - ☐ Other, please specify: ____

    b. If no, what are the primary challenges or obstacles to data linkage?
    ____
    ____
    ____

12. Is there a website that contains information or data from the roadway inventory database (summary reports, statistics, data dictionary, etc.) or that allows online queries of data?

    http:// ____

13. Has your agency conducted, funded, or participated in research regarding data collection and management methods for roadway inventory or pavement monitoring? If so, are there any final reports or other information available?
____
____
____

14. Please select the types of road characteristics and traffic data you collect/manage for each roadway type using the following convention. You may use multiple letters for each box. Leave the box blank if none of the categories apply.

    Categories are:

    - C – collect data **c**omprehensively (e.g., roadway inventory)
    - S – collect data using **s**ampling (e.g., HPMS)
    - A – collect data on an **a**s-needed basis for special studies (e.g., high accident incidence, traffic control device warrant)
    - M – **m**anage and disseminate data including data storage
    - U – **u**ser of data collected by another organization

Traffic Characteristics Data	Types of Roads: Limited Access		Arterials		Collectors		Local
Speed							
Volume							
Vehicle classification							
Vehicle weight							
Axle load							
Axle spacing							
Occupancy or density							
Origin and destination							
Air quality							
Pedestrian counts							
Incident location							
Incident duration							
Type of incidents							
Incident severity							
Traffic control							

15. Please select the types of technologies used to collect traffic data with the following conventions. You may use multiple letters for each box. Leave the box blank if none of the categories apply.

    Categories are:

    S – speed
    V – volume
    D – density
    O – other, specify: ______________________________

Technology	Permanent Location*	Mobile Monitoring**
Manual count boards		
Road tubes, pneumatic counter		
Loop detectors		-----
Video detectors		
Radar detectors		
Laser lidar detectors		
Acoustic detectors		
Magnetic detectors	-----	
Microwave detectors		
Ultrasonic detectors		
Active and passive infrared sensors		
Automatic vehicle identification		
Vehicle probes		
Other; please specify below:		

*Permanent location (e.g., ATMS stations, permanent count station).
**Mobile monitoring (e.g., short-term work zone activities, HPMS).

16. Do you collect origin and destination data?

    ☐ Yes
    ☐ No

    If yes, which of the following technologies do you use?

    ☐ Automatic vehicle identification (travel time, CVO)
    ☐ License plate surveys
    ☐ Other, please specify: ______________________________

17. Do you collect pedestrian counts?

    ☐ Yes
    ☐ No

    If yes, which of the following technologies do you use?:

    ☐ Manual counts
    ☐ Automated methods (please specify): ______________________________
    ☐ Others, please specify: ______________________________

18. Do you collect bicycle count data?

    ☐ Yes
    ☐ No

    If yes, which of the following technologies do you use?

    Manual
    Automated specify: ______________________________
    Others, please specify:______________________________

19. Please specify which technologies you plan to deploy in the next 5–10 years:
    ____
    ____

20. What is the frequency of data collection?

Data Type	Frequency			
	As Needed	Monthly	Yearly	Other, specify:
Speed				
Volume				
Density				
Origin/destination				
Vehicle classification				
Vehicle weight				
Pedestrian counts				
Bicycle counts				

21. What are the primary uses for your traffic operations data?

    ☐ Federal reporting
    ☐ Input to safety evaluation
    ☐ Planning
    ☐ Design
    ☐ Other, please specify: ______________________________

22. Do you receive any data owned or collected by other agencies?

☐ Yes
☐ No

Agency	Data Collected
Toll collection	
Weigh stations	
Large event venues	
Emergency call centers (9-1-1)	
Real-time traffic management centers	
Other DOTs	
Consulting firms	
Other (specify):	

23. Do you archive the data collected from real-time systems (such as real-time traffic sensors) controlled by your agency in the region?

☐ Yes
☐ No

If yes, have you used archived data in your planning activities?

☐ Yes
☐ No

Please specify the usage: ______________________________

24. Do you have any plans to buy more technology for traffic or road characteristic data collection in your region?

☐ Yes
☐ No

If yes, when? ______________________________

Please specify the techonologies: ______________________________

25. Do you face any technical problems with the technology components like loop detectors, video detectors, etc.?

☐ Yes
☐ No

Please specify problems by technology (please state whether your statements are based on field experience or formal operational evaluations):

____
____

26. Do you face any technical problems while using the collected data in various software systems (such as compatibility with the input data requirements, formats, etc.)?

☐ Yes
☐ No
Please explain: ______________________________
____

27. Have increased security concerns in your state shifted traffic collection technologies toward any specific detection or data collection method(s)?

    ☐ Yes
    ☐ No

    Please explain: ____
    ____

Use this space to provide any additional comments or information related to your roadway inventory database or pavement monitoring:
____
____
____
____

TECHNOLOGY DETAILS

The previous questions inquired about the types of data, access, and technologies used to collect the data. In the following section, we would like to obtain additional details on specific technologies or innovations used by your agency. If you use any new, advanced, unusual, or different technologies, software applications, or innovative methods to assist in collecting, processing, or maintaining data, please indicate the type of technology, software, or method in the sections below. We would also like to know if the technologies were developed in-house, by a consultant, or purchased off-the-shelf, and whether or not you have completed any evaluations. Please complete one section for each technology, software application, or method that you believe might be important for this study. Additional pages can be added if necessary. For instance, if you identified previously that you use new radar devices to unobtrusively collect traffic volume data, please provide details for this technology below. Additionally, we are interested in software applications that you use to process or link data, as well as innovative methods such as training or procedures for efficient data collection.

Technology, Software Application, or Innovative Method #1

Descriptive title: ____

Who developed the technology/software/method?
- ☐ Developed in-house
- ☐ Developed by consultant
- ☐ Purchased off-the-shelf
- ☐ Other, please specify: ____

If developed by a consultant/vendor, please provide consultant/vendor contact information in the space below.

Company name: ____
Company address: ____
____
Company phone: ____
Company fax: ____
Company contact: ____
Contact e-mail: ____
Company website: ____

How long have you been using the technology/software/method?

- ☐ <1 year
- ☐ 1–2 years
- ☐ 2–5 years
- ☐ >5 years

Have you completed any evaluations of the use of the technology/software/method?

- ☐ Yes
- ☐ No
- ☐ Evaluation in progress

If yes, did the technologies prove to be cost-effective or improve efficiencies in data collection, processing, or maintenance?

- ☐ Yes
- ☐ No
- ☐ Inconclusive

Is the technology/software/method used locally or statewide?

- ☐ Locally
- ☐ Statewide

If the technology/software/method is used locally, are there plans for implementing it statewide?

- ☐ Yes
- ☐ No
- ☐ Don’t know

Did you experience any integration issues?

- ☐ Yes
- ☐ No

If yes, please briefly explain the issues and resolution: ____

Use the space below to provide any additional comments about this technology, software application, or method:

____
____
____
____

APPENDIX F

Data and Technology Matrix

Data Category/Type	Data Element	Sub-Element	Data Requirements		Potential Data Collection Technologies									
			IHSDM	SafetyAnalyst	Highway Measurement Vehicle	Video-logging	Electronic Crash Report	GPS	Barcode / Magnetic Strip Reader	Plan Sheet / Crash Report Document Scanning	Event Data Recorder	ITS Data Archives	Non-Intrusive Traffic Counters	Satellite Imagery
Road Inventory (Geometric) Data														
General	Segment	Number		x										
		Length		x										
		Location		x										
	Route	Type		x										
		Name or number		x										
	Highway system code			x										
	County number			x										
	District number			o										
	City/town number			o										
	Jurisdiction			o										
	Area type			x										
	Date opened to traffic			o										
Horizontal Alignment	Horizontal tangent	Heading	x		x									
		Length	x		x									
	Horizontal simple curve	Radius	x		x									
		Position	x		x									
	Horizontal spiral curve	Presence	x		x									
		Position	x		x									
	Horizontal deflection	Angle	x		x									
		Direction	x		x									
Vertical Alignment	Vertical point of intersection	Back grade	x		x									
		Back length	x		x									
		Forward length	x		x									
	Vertical tangent	Position	x		x									
		Length	x		x									
	Vertical curve	Position	x		x									
		Length	x		x									
	Elevations		x		x									
Cross-section	Thru lanes	Number (dir)		x	x	x								
		Width		o	x									
	Median	Type		x		x								
		Width		o	x									
	Shoulder	Type	x	x		x								
		Width	x	o	x									
		Slope	x		x									
		Rounding	x											
	Highway cross slope	Normal crown	x		x									
		Superelevation	x		x									
	Pavement type		x			x								
Lane	Thru lane	Number	x		x	x								
		Width	x		x									
	Auxiliary lane	Number		o	x	x								
		Passing	x			x								
		Turning	x			x								
		Two-way left turn	x			x								
		Climbing	x			x								
	Lane offset		x		x									
	Curve widening		x		x									

Data Category/Type	Data Element	Sub-Element	Data Requirements		Potential Data Collection Technologies									
			IHSDM	SafetyAnalyst	Highway Measurement Vehicle	Video-logging	Electronic Crash Report	GPS	Barcode / Magnetic Strip Reader	Plan Sheet / Crash Report Document Scanning	Event Data Recorder	ITS Data Archives	Non-Intrusive Traffic Counters	Satellite Imagery
Road Inventory (Geometric) Data														
Roadside	Bike facilities present		x	x		x				x				
	Driveway density		x	o		x								x
	Foreslope	Slope	x		x					x				
		Width	x		x					x				
	Backslope	Slope	x		x					x				
		Width	x		x					x				
	Ditch	Bottom shape	x		x	x				x				
		Width	x		x					x				
	Obstruction	Offset	x		x					x				
		Presence	x		x	x				x				x
		Side	x		x	x				x				
	Roadside hazard rating		x			x								
Intersection	Number of intersection legs		x			x								
	Approach type (maj/min)		x			x								
	Intersection skew angle		x			x				x				
	Number quadrants w/ limited sight distance		x							x				
	Intersection location			x		x		x						
	Type of intersection			x		x								
	Type of traffic control		x	x		x								
	Major road direction			x										
	Influence zone	Beginning		x										x
		End		x										x
	Offset Intersection	Presence		x		x				x				
		Distance		x						x				
Intersection Leg	Direction			x										
	Number of lanes	Through		x	x	x								
		Right-turn	x	x	x	x								
		Left-turn	x	x	x	x								
	Median type			x		x								
	Signal left-turn phasing			x		x								
	Turn prohibitions			x		x								
Ramps	Ramp	Number		x										
		Location		x		x		x						
		Type		x		x								
		Configuration		x	x	x								
	Type of connection	At freeway		x		x								
		At crossroad		x		x								
	Number of lanes			x		x				x				
	Volume — ADT			x								x	x	

Data Category/Type	Data Element	Sub-Element	Data Requirements		Potential Data Collection Technologies									
			IHSDM	SafetyAnalyst	Highway Measurement Vehicle	Video-logging	Electronic Crash Report	GPS	Barcode / Magnetic Strip Reader	Plan Sheet / Crash Report Document Scanning	Event Data Recorder	ITS Data Archives	Non-Intrusive Traffic Counters	Satellite Imagery
Traffic														
Traffic Operations	Terrain		x	o	x	x								
	Functional classification	Level 1	x	x		x				x				
		Level 2		o										
		Level 3		o										
	Speed	Design	x							x				
		85th	x								actual	x	x	
		Posted	x	o		x				x				
	Volume	ADT	x	x								x	x	
		DHV	x	o								x	x	
		Peak hour	x	o								x	x	
		Growth factor		o								x	x	
		% heavy vehicles		o								x	x	
	Access control			o		x								
	Traffic-way flow			x		x								
	Interchange influence area			o								x		x

Data Category/Type	Data Element	Sub-Element	Data Requirements		Potential Data Collection Technologies									
			IHSDM	SafetyAnalyst	Highway Measurement Vehicle	Video-logging	Electronic Crash Report	GPS	Barcode / Magnetic Strip Reader	Plan Sheet / Crash Report Document Scanning	Event Data Recorder	ITS Data Archives	Non-Intrusive Traffic Counters	Satellite Imagery
Crash Data														
Accident-Level	Accident case identifier			x			x							
	Route type			x			x							
	Route name/number			x			x							
	County number			x			x							
	Accident location		x	x			x	x		x				x
	Location identifier system			x			x							
	District number			o			x							
	City/town number			o			x							
	Accident date	Year	x				x	x			x			
		Year, month, day		x			x	x			x			
	Accident time			x			x	x			x			
	Relationship to junction		x	x			x							x
	Driveway indicator			o			x							
	Light condition			o			x							
	Weather condition			o			x							
	Roadway surface condition			o			x							
	Accident type and manner of collision			x			x							
	Contributing circumstances	Environment		o			x							
		Road		o			x							
	School bus related			x			x							
	Work zone related			x			x							
	Number of vehicles involved			x			x							
	Accident severity		x	x			x				x			
	Alcohol/drug involvement			o			x							
	Tow-away indicator			o			x							
	Run-off road indicator			o			x							
	Pedestrian indicator			o			x							
	Bicycle indicator			o			x							
	Divided highway flag			o			x							
	Day of week			x			x	x						
Vehicle-Level	Initial direction of travel			x			x							
	Vehicle maneuver/action			x			x				x			
	Vehicle configuration			x			x		x					
	First harmful event			x			x							
Person-Level	Driver age			x			x		x					

Abbreviations used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation