

Assessment of the Geographic Information Systems' (GIS) Needs and Obstacles in Traffic Safety

PUBLICATION NO. FHWA-HRT-13-096

OCTOBER 2013



U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
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McLean, VA 22101-2296

FOREWORD

The Federal Highway Administration (FHWA) is focused on advancing the use of evidence-based identification of safety countermeasures and increasing the use of state-of-the-practice safety analyses to support effective safety decisionmaking. Geospatial Information Systems (GIS) offer a unique opportunity to address both of these goals by leveraging various datasets, bringing together disparate information into a common location-based data system. However, GIS implementation is often technically challenging and administratively complicated.

This document summarizes an effort that identifies the level of use of GIS for safety decisionmaking at the State and local level, and uses the results to outline opportunities for FHWA to promote and bolster the use of this technology to improve highway safety. The study utilized a series of resources, including peer exchanges, a comprehensive literature review, and the input of a Technical Working Group. This led to the development of a Marketing, Communications, and Outreach Plan, which included recommend actions for FHWA to incorporate into their safety programs that will support the use of GIS for improved highway safety decisionmaking at the State and local level.

The findings and recommendations from this effort will provide insight into the FHWA's role in advancing the use of GIS-based safety data systems. Ultimately, leveraging these advanced data systems will empower the State and local agencies with the tools needed to make informed and effective safety decisions.

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Director, Office of Safety
Research and Development

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA-HRT-13-096	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Assessment of the Geographic Information Systems' (GIS) Needs and Obstacles in Traffic Safety	5. Report Date October 2013		6. Performing Organization Code
	8. Performing Organization Report No.		
7. Author(s) Bob Scopatz, Nancy Lefler, and Kim Eccles	10. Work Unit No. (TRAIS)		
9. Performing Organization Name and Address Vanasse Hangen Brustlin, Inc. (VHB) 8300 Boone Blvd., Suite 700 Vienna, VA 22182-2626	11. Contract or Grant No. DTFH61-12-F-00069		
	13. Type of Report and Period Covered Final Report, 2012-2013		
12. Sponsoring Agency Name and Address Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296	14. Sponsoring Agency Code		
	15. Supplementary Notes The contract manager for this report was Dr. Craig Thor.		
16. Abstract A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data visually. The objective of this project was to assess GIS practices, needs and obstacles, and opportunities in traffic safety programs and recommend ways to improve the state-of-the-practice in GIS use for highway safety analysis and decisionmaking at the State and local level. The project included a literature review and summary of relevant peer exchanges along with a Marketing, Communications, and Outreach Plan. These resources have been summarized in this final report to help guide future Federal Highway Administration (FHWA) efforts to best support the needs of State and local agencies as they develop and improve their GIS programs for safety. Key findings are that States are not generally using the full capabilities of modern GIS software to support advanced safety data analysis (such as the techniques suggested in the Highway Safety Manual), but that most States are looking forward to enhancing their GIS and making use of advanced techniques in the future. States are aware of the MAP-21 requirements for statewide basemaps and a linear reference system that includes all public roadways, but cite administrative and technical barriers to success. The report includes recommendations for FWHA to help agencies overcome these challenges including tools, marketing and training, and research to fill gaps in knowledge.			
17. Key Words safety data, geographic information system, GIS, LRS, roadway inventory data, traffic data, data collection, crash data, safety analysis		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 47	22. Price

Form DOT F 1700.7 (8-72)

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APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS AND SYMBOLS

DHMS	Digital Highway Measure System
DOT	Department of Transportation
EB	Empirical Bayes
EDC	Every Day Counts
FDE	Fundamental Data Elements (of the Model Inventory of Roadway Elements)
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
HPMS	Highway Performance Monitoring System
HSIP	Highway Safety Improvement Plan
HSM	Highway Safety Manual
IHSDM	Interactive Highway Safety Design Model
iMap	Interactive Mapping Application (San Antonio Bexar County, TX)
LiDAR	Light Detection and Ranging
LRS	Linear Reference System
MAP-21	Moving Ahead for Progress in the 21 st Century Act
MCOP	Marketing, Communications, and Outreach Plan
MIRE	Model Inventory of Roadway Elements
MIS	Management Information System
MLLRS	Multi-Level Linear Referencing System
MMUCC	Model Minimum Uniform Crash Criteria
MPO	Metropolitan Planning Organization
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
PSMS	Pedestrian Safety Management System
RSDP	Roadway Safety Data Program
SPR	State Planning and Research
SQL	Structured Query Language
SWITRS	Statewide Integrated Traffic Records System (California)
TRB	Transportation Research Board
TRCC	Traffic Records Coordinating Committee
TRIS	Transportation Research Information Service
TWG	Technical Working Group
U.S.C.	United States Code

INTRODUCTION

BACKGROUND

A geographic information system (GIS) is designed to capture, store, manipulate, analyze, manage, and visually present all types of geospatial data. GIS combines elements of cartography, statistical analysis, and database technology. It allows users to visualize, analyze, interpret, and understand data to reveal relationships, patterns, and trends. Modern GIS products support all of the functions of a database management system including data capture, database integration, data extraction, and reporting. In addition, GIS products support map-based visualization and advanced spatial analysis. The applications of GIS for transportation, specifically for highway safety (the process of collecting, using, and managing GIS data for safety purposes), appear limitless. GIS is a critical tool that enables agencies to move beyond historical crash locating to geospatial systems that combine diverse data—going well beyond crash, volume, roadway, demographic, and asset data—to advance highway safety. With GIS, decisionmaking becomes more efficient, more informed, and more powerful.

GIS implementations are typically developed in the context of an existing roadway data infrastructure within a State transportation department. In the past, many States' GIS efforts were not well coordinated or compatible with similar efforts at local agencies. As a result, and because of the low level of maturity of the technology, data in any particular GIS were isolated and the maps produced from these systems were often viewed as incomplete, expensive pictures that did not provide much aid in decisionmaking beyond the tools already available. As used in highway safety, early GIS products offered some advantages over the capabilities of a manually-maintained pin map showing the locations of crashes by level of severity but at the cost of extra steps in data entry and map production or printing. Modern GIS software products offer the potential for increased efficiency and flexibility. Modern systems reduce redundant data entry because, in many cases, the relevant data are accessible in the GIS environment through electronic transfer. In addition, the time it takes to specify and produce output has been reduced because modern systems have improved user interfaces and operate on faster computers. For example, as used most often in highway safety analyses, a modern GIS lets users select and filter data so that the map displays only those crashes and features or segments of interest. Alternative views of the same data can be produced quickly by changing the choices available through the user interface. Web-enabled GIS platforms have opened these capabilities to a broad audience, including the general public.

With the availability of more powerful systems, many of the historic barriers to GIS adoption are no longer considered problems. The use of modern tools for data conversion and the implementation of State and national standards, combined with the market dominance of a small number of GIS providers, has reduced the importance of basemap compatibility. However, some barriers, especially those related to cost and resources, still remain.

From August 2012 to March 2013, the Federal Highway Administration (FHWA) convened four National Roadway Safety Data Program (RSDP) Peer Exchanges throughout the country. Representatives from 43 States and Puerto Rico met to share practices, challenges, and solutions to improving their roadway safety data systems. An important component of the discussions was

identifying the multiple uses of GIS and the myriad opportunities for advanced capabilities that GIS provides. Many participants expressed concerns, particularly about educating their senior leadership on the importance of investing in GIS technology enhancements and training, and the 2012 Moving Ahead for Progress in the 21st Century Act (MAP-21) mandate for a statewide basemap to include both State and locally maintained roads.

OBJECTIVES

The objective of this project is to assess the GIS practices, needs and obstacles, and opportunities in traffic safety programs. This information has been summarized into reference information to help guide future FHWA efforts to best support the needs of State and local agencies as they develop and improve their GIS programs for safety. This document serves as the Final Report for the project.

The results of this project are based on several components, including guidance from a Technical Working Group (TWG), extensive literature review including review of the RSDP Peer Exchange proceedings, and development of a Marketing Communications and Outreach Plan (MCOP).

Technical Working Group

The TWG was made up of representatives from the Federal, State, and local levels. They provided guidance during each stage of the project, including review of all project deliverables.

Literature Review

The literature review explored the following topics:

- Current state of practice.
- Data management and analysis tools.
- Emerging practices and tools.
- Obstacles to GIS implementation.
- Areas of needed assistance.

The project team used several key sources of literature to identify information on the above topics, including the National Transportation Library Transportation Research Information Service (TRIS), FHWA Web sites, the Transportation Research Board (TRB) 2013 Compendium of Papers, GIS journals, various GIS conference proceedings, and commercial publications. In addition to the literature review, the relevant discussion from the RSDP Peer Exchanges were compiled and synthesized.

MCOP

The objective of the MCOP is to describe how FHWA can use the results of the project to develop and promote GIS-based traffic safety programs at the State, local, and metropolitan planning organization (MPO) levels. This plan provides information to help guide future FHWA

efforts to best support the State and local agencies as they develop and improve their GIS programs for safety improvement.

This document summarizes the efforts to date and provides FHWA and the GIS user community with the following:

- Summary of GIS current practices.
- GIS needs and obstacles.
- Opportunities for FHWA involvement.
- Recommendations.
- Summary and conclusions.

The first three sections are drawn largely from the literature review, the MCOP and the RSDP Peer Exchange meetings. The conclusions and recommendations sections present the areas of the greatest needs and opportunities including recommendations for future action by FHWA.

GIS CURRENT PRACTICES IN HIGHWAY SAFETY

This section summarizes the current state of practice in GIS for highway safety. It includes discussions of basemaps, local roadway data, the types of data States are using, the use of GIS in highway safety analysis, users of the data, data sharing among agencies, data management, and the strengths and weaknesses of the current GIS practices. Unless otherwise noted, information in this section was obtained from the most recent RSDP Peer Exchanges held in August, September, and December of 2012. (See references 1–4.)

BASEMAPS

The MAP-21 legislation signed into law in July 2012 requires that “Crash, roadway, and traffic data should be linkable by geolocation, i.e., a unique location identifier, on a highway basemap, which is defined as ‘a representation of all public roads that can be used to geolocate attribute data on a roadway,’ [23 U.S.C. 148 (a) (2)].”⁽⁵⁾ Furthermore, The FHWA Office of Highway Policy Information and Office of Planning, Environment, and Realty issued the Memorandum on Geospatial Network for All Public Roads on August 7, 2012, that requires each State to update their linear reference system (LRS) to include all public roadways by June 2014.⁽⁶⁾ Members of the TWG identified this requirement as a problem for many States—some pointing out that it was going to be more difficult to fulfill for States than the MAP-21 requirement to develop a single basemap. Most States currently have a basemap for State-maintained roadways. However, not all States have a basemap that includes local roads. According to the recent RSDP Capabilities Assessment, 15 States have less than half of their local roads on a basemap, including four States which have no local roads on their basemaps.⁽⁷⁾ While approximately two-thirds of the States have a basemap of local roads, this does not necessarily mean they have an LRS for the local roads, or local roadway data. Many western States have large amounts of rural area, and the existing State transportation department local road data, which is not of sufficiently high quality, is better than what is available from the private sources. Conversely, State transportation departments with more urbanized areas might find it cost effective to purchase local road centerline data from commercial providers.

There is extensive research available on developing an LRS, however, NCHRP 20-27, NCHRP 20-27(2), NCHRP 20-27(3) and NCHRP 20-27, Task 302 are among the most comprehensive and provide detailed information for implementing an LRS as well as the costs and benefits associated with implementing an LRS.⁽⁸⁾ The original NCHRP 20-27 report produced a data model that has been used as industry standard since the early 1990s. The data model has been extended over time in 20-27(2), and 20-27(3), to model more complex multi-level linear referencing systems (MLLRS).

Inclusion of Local Road Data

In addition to developing an LRS for local roads, many States are also working to collect local road data. Road data includes geometry and operational attributes on segments, intersections, and ramps. How much local data States have, the source of the data, the format of the data, how it is integrated into the State’s databases, all varies by State. (See references 1–4 and 8.)

Types of Data Being Used

Crash records, traffic volume counts, and roadway inventory information are the primary types of data that States are using in GIS for safety analysis. Many States that are able to geolocate crashes are using GIS for both analytical and visualization purposes. Some States use GIS for visualization only, i.e., visual display of geographically referenced information.

There are resources available that provide guidance on the types of crash and roadway data that should be collected to support safety analysis. The Model Minimum Uniform Crash Criteria (MMUCC) provides guidance on the types of crash data elements agencies should collect and provides suggested attributes for each of the elements.⁽¹⁰⁾ The Model Inventory of Roadway Elements (MIRE), developed as a companion to MMUCC, is a data dictionary of recommended roadway and traffic data elements to support data-driven safety decisionmaking.⁽¹¹⁾ Increasing compliance with MMUCC is a goal of the National Highway Traffic Safety Administration (NHTSA) traffic records improvement process. There are no requirements to comply with the entire MIRE listing. However, as part of the MAP-21 legislation, States are required to collect a subset of MIRE. FHWA Office of Safety determined this subset to be the MIRE Fundamental Data Elements (MIRE FDE).⁽⁵⁾ FHWA Office of Safety released the results of the analysis to estimate the cost to States of collecting the MIRE FDE data.⁽¹²⁾

Use of GIS in Highway Safety Analysis

The predominant use of GIS in highway safety analysis is for identifying high crash locations. This includes identifying hot spots based on crash frequency, plotting high-crash locations to determine the number of crashes on a given segment, using GIS to generate crash clusters for the top 200 crash locations lists, identifying high crash intersections based on certain parameters, and using GIS processes for network screening.

Use of data analysis tools and support varies from State to State, with some States using nationally available tools, and some using State-specific, in-house tools. There are several data analysis tools and methodologies available nationally. These include the Highway Safety Manual (HSM), and software analysis tools to implement the HSM, SafetyAnalyst, and the Interactive Highway Safety Design Model (IHSDM).^(13,14,15) These tools all rely on crash, roadway, and traffic data that can be linked to conduct effective analyses for problem identification and evaluation. According to the RSDP Capabilities Assessment, 33 States reported they are implementing the HSM, 12 reported they are implementing SafetyAnalyst, and 6 reported using the IHSDM.⁽⁷⁾ There are various levels of implementation, from testing the capabilities of the tools to full deployment, including integration into analysis practices. However, the RSDP Capabilities Assessment did not specify the level of implementation of these tools.

The Capabilities Assessment found that States are implementing the HSM and many are actively upgrading their analysis practices. While the HSM provides a common language across the Nation for safety analysis, each State is unique and creates tools to suit their individual needs. Implementing the HSM often requires a change in the formalized decisionmaking process for a transportation department.^(16,17)

The Capabilities Assessment also found that while many States are interested implementing the SafetyAnalyst tool, some find it difficult to do so without first upgrading their existing data or systems.⁽⁷⁾ However, some States have been able to successfully implement SafetyAnalyst, having integrated it into their safety decisionmaking process.⁽¹⁸⁾ Several States have also developed their own advanced tools to conduct safety analysis. (See references 1–4.)

Non-Technical Users of the Data

GIS can serve many purposes for a State, from a visualization tool to an analytical tool. Many States are taking advantage of the mapping and visualization capabilities of GIS to display information to non-technical groups. A review of FHWA’s GIS in Transportation Web site and several State transportation department Web sites indicates that there is a broad use of GIS by agencies for webmapping/visualization. (See references 19–22.)

In addition, FHWA recently funded a study titled “Best Practices in Geographic Information Systems-Based Transportation Asset Management.”⁽²³⁾ The study conducted an interview with eight State transportation departments. One of the products was a matrix which identified three ways that State transportation departments used GIS for a visualization tool for transportation asset management, which are basic visualization data; basic visualization audiences and viewing methods; and external interactive maps.

Additional examples of GIS use identified during the RSDP Peer Exchanges include the following:

- Mapping locations of future projects and hot spots for public meetings.
- Mapping fatalities and impaired driving crashes for regional safety coalitions and law enforcement agencies.
- Mapping safety data for executive level staff.

Data Sharing/Interoperability Among Agencies

Interoperability between State and local agencies varies by State. Some States have great coordination and sharing between the State, MPOs, and local agencies. In some States the MPOs and cities are more advanced than the State when it came to GIS and integrating spatial data with other data. (See references 1–4.)

According to the TWG, some State transportation departments are disseminating crash data to MPOs using data extracts via text files. Coordination among MPOs is needed to ensure that different MPOs are using the data in a standardized format for completing analyses. A TWG member noted that there is a lot of crash data supplied from their State transportation department, but there are many attribute fields, making it problematic when comparing crash analyses among MPOs. In some larger agencies, the GIS data are divided to internal groups within the agency who become responsible for the ownership and maintenance of that data. Other groups within the agency are provided with a user copy of the data for viewing and analysis. This way only a single group can modify the data and ensure the quality of the data.

The sharing of E911 GIS mapping and address databases also varies by location. Some States have legislation or internal policy that prevents the use of E911 data by other agencies.⁽²⁴⁾

Data Management

Data management practices vary by State and among local agencies within a State. In some States, the transportation department's GIS group is responsible for the base layer of State routes; however, the transportation department is not the authoritative data owner for the other roads. In those cases, other agencies may look to the State transportation department to be the data provider, but not necessarily the data owner. Some States have developed data sharing agreements to encourage data sharing between public agencies, including some with signed formal cooperative agreements. (See references 1–4.)

For example, Utah developed an interactive mapping platform based on Esri Roads and Highway software, UPlan. UPlan supports the Utah Department of Transportation's data management efforts by helping to visualize data, track assets, and strengthen transportation planning with better analysis and collaborative information.⁽³⁰⁾ It is a web-based GIS platform that allows users to upload, manage, and share geospatial data between agencies. UPlan contains a variety of data, from environmental, to safety, to maintenance data. Users of the tool can also create and share web-based maps, and generate reports.

Furthermore, FHWA is promoting GIS data collaboration and sharing through its Every Day Counts (EDC) initiative.⁽³¹⁾ FHWA designed EDC to identify and deploy innovation aimed at reducing the time it takes to deliver highway projects, enhance safety, and protect the environment. FHWA is using the UPlan model to evaluate and deploy cloud-based mapping technology for the purposes of improving the quality and speed of project decisions.

Strengths and Weaknesses of Current Practices

The RSDP Peer Exchanges highlighted the strengths and weaknesses of some of the current GIS practices. Examples of strengths include a GIS structured query language (SQL) database that satisfy the agency's needs for multiple user types, a long history of investment in GIS, and a commitment to multi-agency coordination. Examples of weaknesses included concerns over data accuracy and a false impression of high levels of accuracy, lack of resources within the transportation department for quality control, a lack of reliable mechanisms to geolocate crashes, multiple groups with dissimilar capabilities collecting the same roadway data, and paradoxically, a GIS with too many options for displaying and analyzing data. (See references 1–4.)

EXISTING DATA MANAGEMENT AND ANALYSIS TOOLS

Highway Data Management Tools

A 2010 Esri white paper presented a vision of how highway departments could exchange information between users and systems, and overcome the challenges of maintaining and integrating both spatial and non-spatial data.⁽²⁶⁾ The vision described in the white paper became Esri Roads and Highways, a specialized off-the-shelf application for transportation agencies to support highway management and more effective decisionmaking.⁽²⁷⁾ Other available Esri tools helpful to data management include ArcGIS Online, a cloud-based, collaborative content management system for maps, apps, data, and other geographic information. Esri also established a Resource Center to perform complex analyses of highway safety using crash safety analysis tools. These tools perform multivariate analyses that consider traffic volumes and highway characteristics to track the performance of the highway system, and perform time-based analyses to determine highway safety patterns and trends.⁽²⁹⁾ Examples of making good use of these tools include the UPlan system discussed in the previous section.

Note that FHWA does not endorse any one commercial product. These are merely examples of available tools. Additional tools are available through other vendors including, but not limited to, Intergraph, Caliper, and others. AASHTO is also promoting a MLLRS which has been successfully implemented in Iowa.⁽²⁷⁾

As part of the MIRE effort, FHWA developed a prototype management information system (MIS) to test the feasibility of integrating data from the disparate data sources that contain MIRE data into one system to allow for improved integration and safety analysis capabilities. The project team developed, tested, and refined a potential MIRE MIS structure using data from the New Hampshire Department of Transportation. The MIRE MIS effort found that several aspects of the system could tie into a GIS to aid in data entry, querying, and spatial analysis. GIS can also be used to address some of the key concerns of data structure and spatial references changing over time. GIS can provide an absolute spatial reference and provide spatial analysis tools for an alternate way to match data points from different systems, whether these represent the same data collected at different times (e.g., roadway segments from different years), or they represent different data with independent referencing systems (e.g., crash data and bridge data). Adding a GIS component does introduce platform dependencies that may differ from State to State, but regardless of the platform, tying the data into a GIS is an important part of a safety data MIS.⁽³²⁾

Crash Data Collection and Analysis Tools

Crash data collection methodologies are continuously evolving. Most States are moving away from traditional paper reporting to electronic reporting of crash data. The sophistication of electronic reporting systems varies from simply submitting Portable Date Format (PDF) versions of the paper report to systems that support collection of high quality data in a modern database easily shared with the State and other users. The most advanced systems today include “smart mapping” technologies that allow officers to “place” the crash on the State’s basemap. The use of global positioning system (GPS) units or GIS-based “smart-maps” can more precisely determine the location of crashes.⁽³³⁾

NCHRP Synthesis 367 summarized the current state-of-the-art use of technologies for efficient and effective collection and maintenance of data for highway safety analysis by a survey of State transportation departments.⁽³⁵⁾ The most advanced systems support field data collection by law enforcement officers and simplify the task of electronic submission of data from the law enforcement agencies to the statewide crash database. These systems typically incorporate the same validation rules and data edits as the statewide crash data system. This means that the officers in the field are correcting many errors before the report is submitted. This in turn frees staff resources that can be refocused on issues beyond trapping the basic errors that can easily be spotted and corrected through automation. The quality of critical data elements for highway safety, including location information, are improved through the uses of technology that assists the officer and avoids manual key entry of data that can be obtained through pick lists, GPS devices, or, in the best systems, a smart map keyed to the statewide basemap.

Agencies can use GIS in a number of ways for safety analyses including strip analyses along a designated corridor, intersection analyses, sliding scale analyses, and corridor analyses.⁽³⁴⁾ Examples of systems deployed in States include GIS visualization with SQL query capabilities collision diagramming, high crash location analysis, selection and display of individual crash reports, mapping based on crash profiles, linear referencing analysis, and spatial proximity analysis.^(36,37)

In addition to tools developed by States, FHWA has also developed several GIS tools to help advance safety analysis capabilities.⁽³⁸⁾ The FHWA Pedestrian and Bicycle GIS Safety Analysis Tools are a suite of GIS tools that use analytical techniques for a number of pedestrian and bicycle safety issues. The tools included in this suite can be used to develop the following: high pedestrian crash zones, safe routes for walking to school, and safe bicycle routes. The FHWA GIS Safety Analysis Tools offer spatial referencing capabilities and graphical displays for more effective crash analysis. The analysis tools include five separate programs to evaluate crashes as follows:

- Spot/Intersection Analysis.
- Strip Analysis.
- Cluster Analysis.
- Sliding-Scale Analysis.
- Corridor Analysis.

Roadway Data Collection Methodologies

Roadway data collection technology is also evolving. The FHWA MIRE effort explored current data collection technologies for MIRE roadway data.⁽³⁹⁾ Current roadway data collection technologies include:

- Manual data collection either in the field or from straight-line diagrams and as-built plans.
- Manual data entry from ground based imagery such as a photolog, aerial imagery, or satellite imagery such as the Google Earth[®] mapping service.
- Automated data collection using vans instrumented with technologies such GPS or light detection and ranging (LiDAR).
- Airborne LiDAR.

Several factors, including capabilities, accuracy, cost, operational efficiencies, quality control, and post processing requirements impacts States' decisions when selecting an appropriate data collection method. Many States are still using traditional methods for roadway data collection; however, a few States are utilizing more advanced technology such as LiDAR or Mobile LiDAR. (See references 1–4.)

EMERGING PRACTICES AND TOOLS

Research is being conducted in precise roadway mapping using sensory fusion technology utilizing inertial measurement units, feature sensors (RADAR, LiDAR, camera), and existing infrastructure mounted on a mobile data collection vehicle. Such precise mapping is required for next-generation applications such as lane departure warning, curve overspeed warning, signal phase and timing by lane, intersection management, and collision avoidance. These sensors are also being used for feature extraction: Traffic Signal Extraction and Traffic Signal Verification (LiDAR), Curve Extraction and Curve Parameterization (LiDAR).⁽⁴⁰⁾

High-resolution imagery and elevation data can benefit GIS users at all levels of government.⁽¹⁾ Ortho-imagery combined with GIS can provide a 3-D visualization of an elevation profile where a new highway is proposed. Ortho-imagery provides a strong base for the extraction of ground features (e.g., woodlands, impervious surfaces, etc.).

FHWA Office of Safety conducted a pilot MIRE data collection effort that utilized a GIS-based data collection tool to develop an intersection inventory for more than 10,000 intersections for the New Hampshire Department of Transportation. The tool included a model that prepopulated the inventory with data from available transportation datasets, and also included a user-friendly interface to collect the remaining needed data from existing satellite imagery. The use of existing and customized GIS tools proved to be a cost-effective approach to building an intersection inventory.⁽⁴¹⁾ In addition to the intersection inventory tool, there are multiple GIS-based tools used for identifying horizontal curves, including Curve Finder, Curve Extension, and Curve Calculator.⁽⁴²⁾

Castro et al. aimed to develop a GIS-based system that builds vehicle speed profiles, analyzes highway design consistency, simplifies the process of obtaining maps and graphical displays, and facilitates performance of complex analyses in road safety studies.^(43,44) It includes specific tools for the importing of maps and databases and for route object generation, speed profile calculation, the evaluation and graphical representation of consistency, and report generation. Kumaresan et al. identified a methodology to develop a traffic safety analysis system using a GIS environment.⁽⁴⁶⁾ The integrated datasets include vehicle, roadway, crash, and person data. The analyses can be used on a larger scale such as a city, or a smaller spatial extent such as an intersection or roadway segment. The system consists of two parts: the crash data analysis system (i.e., query data based on user's criteria), and the high crash ranking analysis system, which is based on the frequency of crashes or weights specified for different level of severity. The result can be displayed in graphical or tabular format.

Another emerging data collection methodology is utilizing crowdsourcing for collecting transportation data, i.e., "collective data." Crowdsourcing is the process of assembling data or collecting information on a subject using a large, disperse, and potentially uncontrolled group of

people. The “Exploration of the Application of Collective Information to Transportation Data for Safety White Paper” explores the application of collective information in transportation data, particularly in the collection and management of MIRE data. The prevalence of GPS-enabled mobile devices presents a feasible option for acquiring roadway inventory data through crowdsourcing of collective information.⁽⁴⁵⁾

Examples of analytic tools developed by States include combined use of commercial GIS products and open-source programming languages to support advanced modeling and statistical analyses, flexible segmentation, and Bayesian analysis.^(47,48)

In January 2013 the FHWA Office of Safety and Research and Development released a report titled “Data Integration: Investigating the use of Digital Highway Measure System (DHMS) Software to Extract Alignment Data.”⁽⁴⁹⁾ FHWA Digital Highway Measurement Laboratory developed the DHMS software. The Geometric Design Laboratory conducted the evaluation and developed the resulting report under a separate FHWA contract. The study found that DHMS software in its current version was not a suitable use for extracting point-to-geometry (roadway alignment) information collected from mobile data collection systems, such as mobile LiDAR. The study also evaluated existing DHMS post-processing software (it should be noted that this software has not been used since 2008) for use in extracting State data sets that could be used in the IHSDM. It was also concluded the DHMS post-processing software was not a viable method of extracting information in comparison to current commercial practices.

NEEDS AND OBSTACLES

NEEDS IDENTIFIED BY AGENCIES

States participating in the RSDP Peer Exchanges identified several areas where assistance is needed to make further progress in their highway safety programs. (See references 1–4.) The needs align with what was found in the literature review. These needs include obtaining local roads data, integrating and managing the data, training, and learning by example from successful implementations.

Local Roads

GIS, Basemaps, and Local Road Linear Reference Systems

Spatial information describing locations is required on all public roadways based on requirements in the MAP-21 legislation and related guidance provided to States by FHWA. Most States will choose to meet these requirements by implementing their LRS in a GIS with a single statewide basemap and incorporating a single roadway inventory database structure to cover all public roads. There are numerous issues related to local road data collection (both spatial data describing the location and attribute data needed for the accompanying roadway inventory file). Key considerations are the responsibility and cost for data collection, standardizing the methods of data collection, and ensuring the compatibility of several data sources with the centralized statewide repository.

Integrating Local Road Data with a State's Network Data

As part of incorporating local road data into a statewide all-public-roadways system, States may begin to explore the methodologies used in local road data collection to determine if those methods result in sufficiently high quality data. In some States this may require the legislating standards for local roadway inventory and traffic data collection. Elsewhere, States may experience difficulties in obtaining the necessary authority to impose such standards.

Resources are always a consideration as well. Some questions agencies need to consider include: Will the State pay vendors to collect the data? Will locals have to contribute staff or funding to collect data? If the State sets a standard for data collection and the locals can't afford to meet the standard, what is the next step?

Responsibility for data quality management is likely to be shared among the State and local agencies. States must have some ability to review and even edit records submitted by the local agencies, but this may require the development of data ownership and stewardship agreements between the entities.

If the State pays for separate data collection efforts, there is also the possibility that local agencies may use their own data rather than accessing the data in the State system describing their local roads.

Ultimately, these issues result in needs related to interagency coordination as much as they do to needs related to technical solutions to the problems of data sharing (importing and exporting of data from different systems).

Getting Local Agencies to Participate in Data Collection

Gaining the interest and cooperation of local agencies in expanded or improved data collection efforts is a clear and pressing need in most States. The mandated goal of obtaining complete basemap, inventory, and traffic data on all public roads sets up a situation in which States are responsible to have data on portions of the network over which they may exert little or no control. In many States, the hope is that local agencies will take on at least some of the data collection burden, rather than simply relying on the State to collect it for them. At the very least, maintaining an up-to-date basemap requires input from local agencies to identify changes to roadways in their jurisdiction. Collection of traffic and inventory data in a way that will link easily with that statewide basemap sets another challenge. States need help to identify and implement the methods that will work best in their environment. Multiple methods are needed because, even in a single State, not every relationship between a State and local agency is the same.

Demonstrating the Value of Data to Local Agencies

In advance of actually having the data to analyze, it will be difficult for States to show local agencies its value to decision makers. Success stories from States that already have and use local data would help to demonstrate the value of the data. In addition, many States have partial data for local roadways—it is at least possible that a State could use its existing partial data to show the expected value of a more complete dataset.

Information on How Peers are Addressing Data Issues on Local Roads

Beyond the issues of data sharing discussed in the preceding paragraphs, when a State identifies errors in data owned or submitted by a local agency, it needs to have a process in place to rectify those errors. The hope is that corrections will be shared between the State and local agencies, of course, but there are issues to be addressed including synchronizing the State and local databases, ownership and custodial responsibilities for any “official” record, and reporting of analytic results from more than one resource. As seen in the RSDP Capabilities Assessment, many States do not have formal data governance practices in place for the systems and data they own outright. Shared data governance responsibilities complicate this picture enormously, yet few States have any experience with the kinds of processes that would ensure success. The shared data governance of local roadway data will result in new processes likely being developed “on the fly.” States need examples so that they can develop their new data governance policies and procedures in a way that leads to success.

Data Integration and Management

How to Better Integrate Data

As States work to build a single common basemap for all public roads, it is likely that all location-based data will make use of that basemap. Safety analysis requires multiple years of

data for most decisionmaking. Thus, even with new data collection efforts designed to fill data gaps for local roadways, there will be a need to also integrate at least some legacy data if the State and local agencies are to be able to conduct analyses in the near term. The hope is that eventually all local data will be compatible with the statewide systems by virtue of the fact that it is collected using methods that meet the statewide standards. Until that day, however, the State must have ways to incorporate whatever local data it can into the statewide databases. Ideally, this will make maximum use of automated data integration techniques rather than requiring a great deal of unplanned manual effort. States need information on the data integration techniques and their level of success for such efforts as location code assignment, data translation, error checking, and post-acceptance validation and error correction.

Information on How Peers Set Up and Manage Comprehensive Safety Databases

States can learn from case studies featuring successes (and failures) from other States. There is a need to develop this information in a more formal manner.

Identifying Tools to Translate Raw Data into Usable Formats

States need to learn about available tools and techniques for data translation, especially those that help convert information from non-spatial formats into something that can be brought into the GIS environment—landing features and events on the correct locations in the basemap. Depending on the data type, there may be automated methods to accomplish the translation or there may be tools (such as those mentioned in the previous section of the report) that can aid in the manual processes that are required.

Training

Using Safety Funding to Provide Basic GIS Training

States need to know if they can be approved to use Federal funds for GIS training. In particular, there appear to be a variety of training needs and potential audience members from both State and local agencies and at multiple levels of the organizations. States could use guidance and examples of how to use existing funding sources to meet these needs.

How to Efficiently Filter and Analyze Data

At least one GIS user among the Peer Exchange participants expressed concerns about the system presenting too many options. This is most likely an expression of frustration with how difficult it was for this particular user to develop or modify an analysis because the GIS user interface includes options that he did not need or understand. As web-based and widely available GIS implementations become more commonplace, it is expected that at least some users will find the experience daunting. In addition, advanced users of the systems will require specialized training in order to make efficient use of the full range of system capabilities.

Best Practices

Replacing a Legacy System and Implementing a GIS

When States decide to replace a legacy roadway information system with a GIS, there is a period of adjustment and, too often, of recapturing functions and capabilities that the old system had but that were not duplicated in the GIS. Staff members have to learn how to do their jobs using the new system. IT/GIS staffs need information on the functions that the legacy system supported in order to duplicate any analyses or data access capabilities in the new GIS. States could make good use of any guidance or case studies/best practices from those who have already completed this type of system replacement. States could use several levels of guidance, from simple checklists to fully described examples of what went right and what went wrong in GIS implementation and replacement of the legacy system.

Moving from a Tabular Mainframe System to a GIS Data Warehouse

Over years of use, safety practitioners have become accustomed to a system's structure and user interface. When changing from a legacy (often mainframe) system to a GIS data warehouse, users have several novel experiences all at once. While modern GIS databases are still table-based and might look familiar to users, it is likely that the new database structure is not an exact copy of the one that they were used to in the legacy system. Methods of data access may have changed dramatically—shifting from a limited set of options users knew well to a more powerful, yet unfamiliar system based on SQL or other query-building method. The number of choices may also have expanded as the GIS may include numerous spatial datasets beyond the two or three most users have experienced on a regular basis. There are obvious training needs for users who need to perform specific tasks in the new system. There may also be needs for IT/GIS staff to understand and design standard queries and reports to serve various user groups. States could use guidance and examples of how other States have managed this transition.

Using GIS for Safety Analyses

The number and variety of safety analyses that a GIS can support are quite large. With training, practice, and IT staff assistance, most users will quickly learn how to perform the routine analyses GIS that they have previously performed in the legacy system environment. The advantage of GIS is that it can support more analyses, especially geospatial analysis, that would have been difficult or impossible using the legacy system. States could learn from each other how best to use GIS in support of an expanded set of analyses. State and local staff could make use of training on the functions supported by the GIS.

Administrative Obstacles

Many States are facing administrative obstacles, whether they have been using GIS in highway safety for years, or are just starting out. The major administrative obstacles States are faced with are lack of resources (money and personnel), not having a GIS champion or leadership support, differing business plans between agencies, identifying GIS as a priority within the State, and determining data ownership and responsibility. MAP-21 dramatically increases funding levels to support the State's Highway Safety Improvement Plans (HSIP). Data improvement efforts are

eligible for HSIP funding. This additional funding along with the MAP-21 legislative requirements may help to address some of these obstacles.

The most common problem expressed during the RSDP Peer Exchanges was determining the responsibility for data management of the data and the GIS. (See references 1–4.) Some State transportation departments do not have a GIS section and the responsibility has fallen on the safety office to manage the system, though it is not the right fit. Other States have different groups and offices that use and contribute data to the system but communication between them is lacking.

A lack of leadership support is also a major obstacle to implementation. During the RSDP Peer Exchanges, participants said that getting management to buy into developing GIS capabilities is challenging and that overall GIS awareness is lacking. One participant said that finding the right person with the right knowledge to lead the process is a challenge. Another noted that some of the data products (e.g., maps of crash and volume data) were discontinued because leadership thought it was simply a map and was not aware of the analytical usefulness of the data. States need a tangible way of measuring benefits to justify the expense of creating and integrating tools.

Stovepipe organizations make coordination and data sharing difficult. They can lead to unclear ownership and responsibility for system and data maintenance. States need clear lines of authority for both the systems and the data.

There were similar discussions of administrative obstacles at a 2011 GIS Peer Exchange in Cambridge, Massachusetts.⁽⁵⁰⁾ States expressed the concern that the biggest challenge is not the technology itself, but the people and politics behind it (e.g., disagreements, retirements of key individuals). Other related impediments are the changes in Federal requirements, which trickle down to all levels and require changing or updating the business systems.

Technical Obstacles

States are faced with a number of technical obstacles. These include data management, data storage, data quality, incompatibility of data sources, different geo-referencing systems, and varying data definitions and formats. While MMUCC and MIRE provide guidance for data standardization in crash and inventory data, respectively, compliance with these guidelines varies by agency.

The 2011 GIS Peer Exchange also reported difficulties with data storage.⁽⁵⁰⁾ An obstacle for States that obtain data from many sources is storing these data in a single format that is accessible and usable for users across agencies.

Another technical obstacle is data quality. States that rely on data from other agencies, and even from their own State transportation department, are struggling with quality issues. For example, one participant expressed concern about what is actually the “ground truth,” and having transportation layers for the entire State.⁽²⁾ Different types of data collected, the frequency of collection, the level of granularity, and the reference system used, all pose challenges when integrating data from various sources.⁽¹⁾ Some data may be incompatible with GIS software, and it is a time-consuming process to convert data into a layer in the GIS. Incorporating data from

different LRSs also proves to be a significant obstacle as each LRS has to be maintained separately and in coordination with the GIS.⁽⁵¹⁾

FHWA Office of Safety developed guidance on using performance measures to help improve roadway data quality.⁽⁵²⁾ FHWA Office of Safety has also developed the Roadway Data Improvement Program (RDIP) to help provide training directly to States for data improvement.⁽⁵³⁾ However, these resources have only recently been released and agencies may not yet have had the chance to participate.

Integrating GIS into safety decisionmaking generates a need to address the needs of non-technical users. This may take the form of technical training for GIS users, but another growing need is for ways to make the GIS more accessible to users who lack the technical training or expertise required to make best use of today's GIS products. It is clear that GIS is not intuitive for those who do not use it frequently. Some States have been able to solve this problem by creating web-based interfaces and map displays that are more user-friendly for those not trained in GIS software. However, other States expressed during the RSDP Peer Exchanges that the GIS itself needs to be more user friendly, and training should be required for engineers. One participant expressed concern that when an agency has specialists in-house, they develop their own GIS applications but there are usually only a few people who know how they work and how to maintain and use the tools. This knowledge should be transferred to more people across groups so not to lose specialization if certain staff members are no longer available.

At a 2012 Summit of the National Transportation Safety Board, DOT identified obstacles associated with the current Highway Performance Monitoring System (HPMS) requirements. These include no requirements for States to work with neighbors on connectivity; lack of resources available for aggregation, assembly, and publication of a nationwide dataset; varying level of data quality and accuracy from State to State; and little independent verification of street centerlines.⁽⁵⁴⁾

OPPORTUNITIES

The literature review and Peer Exchanges also identified the following areas where FHWA leadership can help advance GIS to improve highway safety:

TOP-LEVEL GUIDANCE AND MARKETING

Set a Strategic Vision

FHWA should set a strategic vision for GIS and geospatial data sharing to make sense of how it all fits together. This could take the form of a white paper describing how a system could be designed to meet the needs of State and local safety professionals for broad access to crash, inventory, traffic, and other data in a shared environment. The white paper could address practical issues such as a data and system champion, data collection, data ownership, data and system maintenance, as well as the technical implementation issues.

Demonstrate the Value of GIS to State Traffic Records Coordinating Committees (TRCC)

In order to build a broad user community, the GIS owner needs to expand its user base beyond traditional engineering uses of the system. There are stakeholder groups—most notably the TRCC—charged with coordination, strategic planning of system improvements, and promoting data quality and data-driven decisionmaking. The TRCC, and similar organizations, are ideal advocates; reaching out to peers and providing a forum for the exchange of ideas within a State. A GIS guide for TRCC members is needed to help non-engineers and non-technical TRCC members understand the power of the GIS implementation in their State.

Provide Peer Successes

States prefer to learn from peers, especially with success stories but even examples of lessons learned from failed implementations are useful and informative. The costs of GIS implementations are high enough that the system's purchase and maintenance must be thoroughly justified and approved. Examples from States that are further along in the process are needed by States that are just starting out, or those that have hit a snag.

SPECIFIC SYSTEM AND DATA REQUIREMENTS

Prescriptive, Clear, Uniform Guidance

State practitioners are asking for prescriptive guidance in order to help make the case for improvements in data and systems. As long as that the guidance is clear, makes sense and is the same for every State, it will help to justify the resource needs identified by the system owners.

Uniform Data Requirements

States are generally willing to report data to FHWA. They wish to be reassured that their data are comparable to that from other States because they know comparisons will be made. When the data are comparable, States also believe that there is a benefit because they can access benchmarks from other States as a way to judge their own performance and develop justifications for programs to meet needs identified as a result of those comparisons.

HPMS Requirements

States recognize that some of the Federal data requirements are evolving and they also shared concerns over exactly how much data they must report for the local system. As a companion to this, States also express concern over data quality requirements, especially for those portions of the system that they do not directly control. States would benefit from guidance on data quality requirements. In addition, there is some overlap between HPMS requirements and other Federal requirements including the MAP-21 safety data related requirements. There are potential opportunities to support states in collaborating/coordinating needs and resources to reduce overall resources needed to meet these individual requirements.

Consistent Data Definitions

States would benefit from coordinated data requirements that share basic data definitions and reporting periods as they could then satisfy multiple requests with a single set of output reports. This suggestion could be expanded to all data requests coming to the State transportation department from DOT administrations—where similar data items are being requested, the States would like to have a single unified data definition and reporting period established so they can do the work once.

Set National GIS and Performance Measurement Requirements

In keeping with the States' call for more prescriptive guidance, several participants requested that FHWA develop a national set of GIS requirements for States to meet. Included would be the requirement for States to have a GIS that integrates all public roadways and incorporates, at a minimum, the traditional data sets used in highway safety: crash, roadway inventory, and traffic volume. This would also include a standard set of performance measures for States to report.

RECOMMENDATIONS

The following recommendations are based on the findings of this study. They are written primarily as actions that FHWA could take, but all would have State and local practitioners as the primary audience. It is further recommended that FHWA develop the recommended tools and marketing materials and undertake the research projects in cooperation with States and select local partners.

MANAGEMENT

In order to fulfill its role in promoting GIS adoption and use in highway safety analysis and decision-making, FHWA will need processes in place by which it can define and measure success. The following recommendations are intended to address this need and are considered necessary, high-priority items to be addressed in the near term.

Define the Criteria for Success

FHWA should establish performance measurement criteria for each of several sub-goals related to the overall goal of GIS adoption. The sub-goals include:

- Develop basemaps.
- Collect local road data.
- Use the data for highway safety visualization.
- Use GIS to support highway safety analysis.
- Provide spatial analysis and data for non-technical users.
- Encourage performance measurement and improvement.

These can be measured based on the number of States that have achieved each goal. The measurements, in turn, would provide the basis for FHWA to judge the current status of GIS implementation and use Nationwide.

Establish a Timeframe for Implementing Goals

MAP-21 and FHWA guidance to the States provides the basis for achieving each of the components of the overall goal of GIS adoption and use. There are early actions that must take place within the next year (e.g., according to HPMS requirements, each State must have a unified LRS including all public roads by the due date of June 15, 2014). Other achievements will take place over the next several years.

Develop a Mechanism for Tracking Progress

In order to track progress efficiently, FHWA will need data from the States. This requires that States cooperate with FHWA in reporting the measurements that relate to the defined criteria for success. FHWA must have a method in place for collecting and reporting this information.

TOOLS

The following are ideas for software and interactive media that would help users produce useful results either with a sample data set or, ideally, with data from their own jurisdiction. These are drawn from the literature review and RSDP Peer Exchange discussions.

Performance Measurement

This recommendation is for FHWA to develop the management practices described earlier in this report. In particular, FHWA should establish a set of performance criteria related to the major activities that States and local agencies will need to complete on the way to meeting the national goals for GIS implementation and use. Peer Exchange participants suggested that FHWA take the lead in this area, but it is also clear that FHWA cannot measure performance without direct input from the practitioners. The management process relies on measures of State and local actions and performance. As a result, FHWA will also take on the role of encouraging States to measure their own performance for the States' own use, and also to provide relevant data to FHWA.

Highway Safety Management Tools for Data-Poor Environments

This tool would function much like SafetyAnalyst, but with a focus specifically on States and local agencies that lack the required data for a more robust tool. As a preliminary vision, this tool could incorporate a series of reasonable default values or ranges of values to substitute for those data items that may be lacking. For example, if an agency cannot reliably link their crash and intersection data for the entire network, this tool might give them the option of using default baseline measurements. Likewise, if detailed traffic volume data are lacking, the software might provide a selection of standard values based on qualitative descriptions that the user might provide (e.g., “high volume,” “low volume,” etc.). The goal in developing this tool would be to provide a resource for States and local agencies that are not able to implement advanced analytic methods in their safety programs specifically because some aspect of their data is sub-standard. These users could still benefit from learning and applying advanced analysis methods if there was a way for them to make reasonable assumptions and feed the data models appropriate values that are good enough to support estimation. It is likely that the tool would work best by supplying a range of results rather than a single best estimate.

Tutorial on Advanced Safety Analyses Using Geospatial Data

This tool would ideally take the form of practical training using State data to produce immediately useful results and reports. As noted in earlier sections of this report, some States are using GIS to support advanced analyses incorporating Empirical Bayes (EB) and various statistical modeling techniques. These successful uses of GIS capabilities go beyond the basic visualization functions that are common to most State transportation department implementations. A tutorial on using geospatial data in advanced safety analysis could be viewed as a supplemental to the next recommended tool—the HSM step-by-step guide.

HSM Companion: Step-by-Step Guide to Advanced Analytic Techniques Using GIS

The HSM is a groundbreaking resource in traffic safety analysis. It contains detailed guidance on valid techniques for network screening, countermeasure selection, and program evaluation. Unfortunately, the HSM does not contain a sufficient number and variety of worked out examples—and none of the examples includes use of a GIS. In many cases the presentation skips steps such that only a person who is already familiar with the analytic technique can reliably follow the example. A step-by-step guide to the advanced analytic methods presented in the HSM would serve several purposes. First, it would allow safety practitioners to learn the techniques reliably and give them the confidence they need to apply those techniques in the future. Second, it would serve as a primer for decision makers who want to know the details of the techniques so that they may better understand and interpret analytic results they are expected to use. Third, by addressing GIS support for HSM-style analyses, the tool would present the mechanics of accomplishing a specific task. Finally, the tool would serve as an educational resource for the future as new techniques and variants of existing techniques are developed, step-by-step guidance could be added for those as well.

Smart Map Technology for Crash Reporting

Significant savings in coding crash location result from the adoption of automated tools to aid police officers in recording this information. The best of these tools are “smart maps” which provide the officer with a point-and-click map interface using the statewide basemap. When the officer zooms in and clicks on the location of the crash, the smart map returns the appropriate on street, direction and distance from the nearest cross street, the latitude/longitude coordinates, and the correct location code to place the crash within the LRS. As a result, the crash automatically “lands” in the correct location when the data are transferred to the statewide GIS. Manual location coding is greatly reduced or eliminated, thereby freeing resources for quality control efforts.

MARKETING AND TRAINING

The following are ideas for marketing and training aimed at promoting GIS use and encouraging State and local agency cooperation in data collection. The ideas are drawn from the literature review and RSDP Peer Exchanges as well as the Marketing, Communications, and Outreach Plan presented to FHWA as an earlier product from this project.

Standardized, Periodic Reporting of Performance

Sharing performance measurement data with States and local agencies is a powerful marketing strategy. It not only communicates the goals and expectations for each measured item, but it also encourages a culture of performance measurement—management “by the numbers.” FHWA clearly has an interest in making sure that States develop performance measures related to GIS implementation and use since those measurements would serve as the basis for FHWA’s own performance measurement data.

National Standards/Guidance for Safety Data Collection, Management and Use

There are a large number of issues related to GIS implementation for which States have asked for guidance and national standards. Later sections of this report describe several such issues and provide recommendations for developing targeted materials for the identified audiences. FHWA is well situated to lead the effort to develop national standards and guidance, in cooperation with State and local partners as well as other areas within DOT.

Peer Exchanges

The peer exchange methodology is popular with States. Learning from peers involves a level of trust and shared experience that facilitates free information sharing and promotes valuable contacts among the participants. States specifically asked for more peer exchanges especially including those States that have solved some of the problems associated with GIS start-up, implementation, and maintenance.

Training for Specific Audiences

Later sections of this report also provide ideas for training needed for specific target audiences. FHWA can take the lead in developing content for identified courses with the cooperation of State and local practitioners.

Alternative Methods of FDE and Geospatial Data Collection

FHWA has information on successful data collection efforts in the States and can share descriptions of alternative methodologies with States. For example, there are several resources that FHWA developed as part of the MIRE MIS effort, including the “MIRE Element Collection Mechanisms and Gap Analysis” and “MIRE MIS Lead Agency Data Collection” reports.^(39,41) These and other resources are available on FHWA’s RSDP Web site.⁽⁵³⁾ States could also share lessons learned from their experiences collecting and managing the data. The ideal set of materials for this product might include brochures as well as technical reports that provide details on individual State’s programs.

GIS Primer for Agency Executives

Agency executives have two important roles with respect to decisionmaking and GIS: as users and for oversight/management. As users, agency executives may be using analyses prepared using GIS in order to decide on agency priorities and sign off on program-level priorities. The executives also must approve GIS implementation or expansion projects and provide top-level support for these efforts. As noted in the Peer Exchanges, there are some States where upper level support for GIS is not strong at least in part because the managers and directors do not fully understand the benefits of GIS. At the State level, especially before GIS is fully implemented, it can be difficult for the technical staff to demonstrate a quantitative benefit of GIS—especially one that converts easily to a monetary benefit that can be compared directly to the costs of the system or its expansion. This is where FHWA could play a crucial role in bringing together reliable information from multiple States that already have successful GIS implementations. The goal would be for FHWA to develop a briefing and companion materials (the primer) for an audience of top-level executives at State and local agencies. The aim is that this primer would

encourage investment in GIS and help to promote expanded, more expert-level, use of the systems.

Local Agency Benefits and Costs of Standardized Data Collection and Data Sharing

State practitioners need a way to convince local agency decision makers to cooperate with new data collection initiatives and methods. This set of marketing products would address that need by providing local decision makers with information from peers and external experts on the costs and benefits of the proposed data collection efforts (e.g., the FDE on local roadways). By combining peer and expert advice on data collection and use, FHWA could develop products that directly address the needs for reliable information at the local level. Delivery mechanisms might include peer exchange meetings, presentations, webinars, and static materials (brochures and reports).

Best Practices, Case Studies, and Implementation Guides

States have asked for resources that address their need for guidance on how best to implement GIS, geospatial data collection, and advanced analysis. These could take the form of a series of related (branded) products including brochures, detailed reports, recorded and live presentations, and live or web-based peer exchanges. The goal would be to develop whatever guides the States identify as necessary and make the materials available individually and as a package.

Guide to Funding Options and Levels

States have requested information on how to pay for GIS implementations, expansions, and lifecycle maintenance costs. FHWA could develop this guidance to advise States on the available funding sources. Ideally, the guidance would cover the level of available funding, application process, timelines, selection criteria, requirements, and restrictions for each funding source.

RESEARCH OPPORTUNITIES

In developing the recommendations and exploring the opportunities for FHWA action in promoting GIS and local roadway data collection, the following research needs emerged as ideas for ways to fill the gap between current knowledge/practice and the States' requests for detailed guidance. The following research needs are presented as ideas that would help FHWA develop products and promotional materials to advance the use of GIS nationally.

National Strategy

This document can be viewed as setting the stage for FHWA to develop a national strategy for GIS use. This is a job that FHWA can lead but cannot accomplish alone. It is therefore recommended that FHWA work with national partners (e.g., AASHTO and TRB) to empanel State, local, and national experts to serve as a working group to develop a statement of national vision, goals, actions, and priorities aimed at increasing the value and use of GIS for safety analysis and decision-making.

Promising Practices

Success stories are a key source of content for the marketing, communications, outreach, and training activities identified in this document. As time passes and the GIS implementations of today reach maturity and/or undergo upgrades, it will be important to refresh the materials that FHWA uses to get the message out. There is an ongoing need for knowledge about adoption of the latest technology and practices—what are the challenges, how are they overcome, what benefits can be expected, what are the costs? One possibility would be to create a clearinghouse of promising practices and to make the information accessible to all interested parties. This would also be an excellent resource for future peer exchanges. This could be considered as an expansion of the existing FHWA Safety Data Community of Practice to include GIS-related topics.⁽⁵³⁾

Alternative Approaches for Data Collection Benefit/Cost

As States work to comply with the MAP-21 requirements, they will look for the most cost effective ways to collect the necessary data and develop the needed basemaps and LRSs. As a companion recommendation to the promising practices research opportunity described above, States could also benefit from a clearinghouse of data collection tactics and to have that information available for peer exchanges as well. This work would ideally produce a comparable set of benefit/cost ratios for the alternative approaches. Throughout highway safety there are few analyses showing the benefits of data in the quest to reduce injuries, fatalities, and costs. Few States track the costs of having specific data resources available (e.g., crash or roadway data) and there are none at present that routinely measure the use of the data in support of safety decisionmaking as a way to make the monetary connection between “having the data” and “saving lives.” The vision for this research is to develop as many examples as possible of the benefits of data presence as a way to demonstrate that data collection has a favorable benefit/cost ratio. Existing work on this issue that could be expanded includes the MIRE Fundamental Data Elements Cost-Benefit Estimation.⁽¹²⁾

Benefits and Costs of Optional Approaches to GIS Implementation

States are a natural laboratory for optional approaches to GIS implementation. Each State has a different approach, and within each, multiple methods of local interaction and implementation are often found. States that are on the earlier end of the process—working through the decision process—would benefit from a simple listing of the pros and cons of each approach. This could also become part of the suggested clearinghouse, and would generate much of the desired content for training State practitioners.

Life-Cycle Maintenance and Support

States need more complete information than is currently available on the life-cycle costs of a GIS and maintenance of geospatial data. Decisions by State agency leaders will have an impact on annual, ongoing costs of running their systems. In many cases, however, there is only partial information or estimates available on the longer-term costs and benefits of GIS. Identifying the costs up front is important because States need to have the money in place in advance in order to be sure they can keep the system running and meet whatever obligations they take on as part of

GIS implementation. Knowing the benefits helps to justify the costs. Understanding the costs of data archiving will play an important role in determining the overall costs of life-cycle maintenance and support.

Identifying Tools to Help Transform/Translate Raw Data into Usable Formats for GIS

One of the many optional methods of obtaining data to populate the new statewide roadway information database is to use existing data resources. Unfortunately, many of the existing resources exist in data formats or raw data forms that do not readily translate into a geospatial database suitable for uploading and automatic location coding in a GIS. There may be tools already available that help with the translation process or tools may be developed in one State that could be useful to other States. Research is needed to describe what States are doing now and what is possible given the level of technology.

Use of GIS for Safety Analysis

This is part of the primary objective of this project—to promote use of GIS for safety analysis, especially advanced safety analysis. There is a need to expand upon what was identified in the literature review regarding examples of successful practices and for detailed step-by-step guidance on how to accomplish the goal. FHWA could conduct research among those States that have strong GIS and analysis capabilities to describe the methods and contributing factors to their successes.

Future of GIS as a Data Warehouse

Generally, this report has concentrated on the three traditional data sources required for highway safety analysis: crash, roadway inventory, and traffic volume data. As GIS implementations mature, and analytic capabilities (and interests) expand, it is expected that States will want to incorporate additional datasets into safety analyses. MAP-21 specifically identifies the value of linking citation/adjudication and EMS/injury surveillance data to the traditional highway safety datasets. A likely early success for this expansion is emergency medical service data along with other patient treatment information. This family of data sources (EMS, trauma registry, in-patient hospital records, emergency department records, death certificate data, and rehabilitation services data) is generally referred to as the “injury surveillance” system. In some States, injury surveillance data are already being merged with crash and roadway data to help quantify the consequences of injuries resulting from crashes. This is useful for roadway safety decisionmaking because the injury surveillance data include accurate and reliable measures of costs associated with treating crash-related injuries. With this information, State safety analyses gain in precision and relevance because the outcome measures are based on actual data from people injured in crashes in the same State (or other political jurisdiction).

SUMMARY AND CONCLUSIONS

SUMMARY

The preceding sections of this document describe current practices, identify needs and obstacles, and present a series of ideas for FHWA to pursue in promoting GIS nationally.

Current Practices

Current State GIS practices fall into the following categories:

- Developing basemaps.
- Collecting local road data.
- Using data types collected.
- Performing highway safety analysis.
- Providing data for nontechnical data users.

Needs and Obstacles

States identified several categories of needs, including the following:

- Local roads.
 - Establishing GIS, basemaps, and local road linear reference systems.
 - Integrating local road data with a State's network data.
 - Getting local agencies to participate in data collection.
 - Demonstrating the value of data to local agencies.
 - Obtaining information on how peers are addressing data issues on local roads.
- Data integration and management.
 - Understanding how to better integrate data.
 - Obtaining information on how peers set up and manage comprehensive safety databases.
 - Identifying tools to translate raw data into usable formats.
- Training.
 - Using safety funding to provide basic GIS training.
 - Filtering and analyzing data efficiently.
- Best Practices.
 - Replacing a legacy system and implementing a GIS.
 - Moving from a tabular mainframe system to a GIS data warehouse.
 - Using GIS for safety analyses.

In addition to these needs, States identified administrative and technical obstacles to GIS adoption and expansion.

Opportunities

There are several suggested areas for FHWA assistance, which fall into two main categories. States would like FHWA actions to include the following:

- Top-Level Guidance and Marketing.
 - Setting a strategic vision.
 - Demonstrating the value of GIS to State TRCCs.
 - Providing peer successes.

- Specific System and Data Requirements
 - Providing clear, prescriptive, and uniform guidance.
 - Establishing uniform data requirements.
 - Establishing a HPMS requirement.
 - Creating consistent data definitions.
 - Setting national GIS and performance measurement requirements.

Recommendations

The following lists the recommendations addressed in this report and the MCOP. At the top level are the program management recommendations designed to help FHWA design and monitor a national program aimed at promoting GIS use in traffic safety decisionmaking.

The MCOP also presents recommended direct actions that FHWA can take in order to actively assist States' GIS adoption and use. The challenges and current practices, along with direct statements of participants in the RSDP Peer Exchanges point to several activities that FHWA may wish to pursue. The recommendations fall into three main categories: tools, marketing and training, and research opportunities. One clear point of overlap is that these categories are not mutually exclusive. An analytic tool can serve a marketing purpose; research results can be used in marketing campaigns and to develop or refine analytic tools.

- Tools.
 - Performance measurement.
 - Highway safety management tools for data-poor environments.
 - Tutorial on advanced safety analyses using geospatial data.
 - HSM Companion: step-by-step guide to advanced analytic techniques using GIS.
 - Smart map technology for crash reporting.

- Marketing and Training.
 - Standardized, periodic reporting of performance.
 - National standards/guidance for safety data collection, management, and use.
 - Peer exchanges.
 - Training for specific audiences.
 - Alternative methods of FDE and geospatial data collection.
 - GIS primer for agency executives.
 - Local agency benefits and costs of standardized data collection and data sharing.
 - Best practices, case studies, and implementation guides.

- Guide to funding options and levels.
- Research Opportunities
 - National strategy.
 - Promising practices.
 - Alternative approaches for data collection benefit/cost.
 - Benefits and costs of optional approaches to GIS implementation.
 - Life-cycle maintenance and support.
 - Identifying tools to help transform/translate raw data into usable formats (e.g., curve and grade data) into a GIS layer interface.
 - Use of GIS for safety analysis.
 - Future of GIS as a data warehouse.

CONCLUSIONS

Taken together, the preceding points paint a picture of rapid transition in the States and at local agencies. GIS implementations are expanding as States plan and implement major changes in the data they store and use in the GIS. In response to the MAP-21 requirement for States to have a complete basemap of all public roadways, States are preferentially adopting a vision of a unified system with a single linear reference system, implemented within a GIS framework, and supporting (at a minimum) traditional safety analyses based on crash frequency and rate. At the same time, States are working to adopt advanced analytic methods like those described in the HSM, and supported by tools such as SafetyAnalyst and the IHSDM, among others. Some States are building their own tools while others are adopting or adapting tools that are already available. States would welcome help in this area, not just to aid them in the search for best practices, but also in identifying and promoting tools and advanced analytic techniques. States do want to point to GIS in general as the best way for them to meet new requirements and aid in their own efforts at advanced analysis.

Another clear conclusion is that States need guidance, models, and direct assistance in working with the local agencies that are likely to be the source of much of the new data that needs to be collected in order to meet the MAP-21 requirements. While many local agencies have sophisticated data systems of their own, the imposition of statewide and national standards on local data collection efforts is likely to require marketing. States will need to be able to communicate the advantages to locals. FHWA is uniquely positioned to develop the materials that would describe, and hopefully quantify, those benefits. States and locals will also be keenly interested in knowing the potential costs of the new data collection requirements and in learning about alternative methods of collecting the data, especially if those methods can save some money.

Finally, throughout the course of this project, the project team identified research needs that FHWA could choose to pursue. These are generally aimed at filling gaps in knowledge about the benefits and costs associated with each of the many choices available to States during GIS implementation as well as research aimed at testing the sufficiency of alternative methods of data collection, data integration, and data analysis in the geospatial data environment.

GLOSSARY

Basemap	The digital representation of a geographic area (e.g., a State) as implemented in a geographic information system. In highway safety it is a digital representation of all public roads that can be used to geolocate attribute data on a roadway.
Bayes (Bayesian)	A family of statistical analytic techniques that reduces or eliminates the contribution of regression-to-the-mean in evaluations of changes over time.
Centerline	As used in a linear reference system: A geographic representation in which each roadway is represented as a single line (the centerline) and locations along that centerline are coded as the distance along the roadway (centerline) from a fixed starting point.
Cloud-based	A data storage and retrieval environment that is shared broadly among all users rather than being centrally located on a server residing in a single location (such as the data custodian's information technology area). Cloud-based storage is generally accessible via the internet.
Crowd-sourcing	A method of collecting and sharing data that is derived from a large number of (typically public, anonymous) sources such as all users of GPS-enabled smart phones or all users of a smart phone software application.
Geolocate	The process of assigning location codes (e.g., latitude and longitude coordinates, or a location code from a linear reference system) to the data recording a roadway attribute or event (e.g., a crash).
Geolocation	The mapped location of an attribute or event on the basemap. See also "geolocate."
Geoprocessing	In a geographic information system, geoprocessing refers to tools or software algorithms/routines used to perform functions such as assigning data items to the correct location on the basemap and translating between two or more location coding schemes (e.g., different linear reference systems).
Geospatial	The geographic, spatial relationships among items (such as roadway attributes and crashes). Used interchangeably with the terms "geographic" and "spatial." May also refer to analysis of such relationships (e.g., geospatial analysis).

Linear Reference System	A method of assigning roadway attributes, features, and associated events (e.g., crashes) to a specific location along the length of the roadway. In a linear reference system, locations are defined as the distance along the roadway from a fixed point such as the beginning of the roadway, a county or State line, or some other landmark.
Ortho-imagery	A photographic image (usually aerial) which has been corrected to remove distortion caused by optics, angle, and elevation to achieve accuracy sufficient to allow accurate measurement of features and distances.
Photolog	An database of still images (photographs) showing roadway attributes tied to a State's location referencing method (e.g., the linear reference system and/or GIS) based on location codes or spatial coordinates (latitude/longitude). Typically, a photolog will contain images spaced a standard distance of travel along the roadway.
Videolog	A photolog implemented with continuous video-based imagery rather than discrete photos. As with photologs, the images in a videolog are usually coded with the location reference and/or spatial coordinates.
Visualization	Visual display of geographically referenced information.
Webmapping	A feature of web-based GIS tools that enables users to specify and view maps via a Web site.

ACKNOWLEDGEMENTS

The project team would like to thank the FHWA project manager Dr. Craig Thor and the following individuals who graciously served as Technical Working Group members providing invaluable guidance for this project.

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