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SYNTHESIS 335

Pavement Management Applications Using Geographic Information Systems

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD
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Pavement Management Applications Using Geographic Information Systems

A Synthesis of Highway Practice

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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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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

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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.

Information exists 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*.

The 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 report of the Transportation Research Board documents the state of the practice and knowledge of pavement management systems (PMS) using Geographic Information Systems (GIS) and other spatial technologies and discusses how the technologies have been combined to enhance the highway management process. The synthesis reviews the principal issues related to PMS data collection, integration, management, and dissemination; applications of spatial technologies for map generation and PMS spatial analysis; and implementation-related issues, including approaches used for integrating PMS and GIS and the different tools used to support pavement management decisions.

This synthesis contains information drawn from a variety of sources, including a literature review, an electronic survey of state practices, and follow-up interviews with a select number of state transportation agencies.

A panel of experts in the subject area guided the work of organizing and evaluating the collected data and reviewed the final synthesis report. A consultant was engaged to collect and synthesize the information and to write this report. Both the consultant and the members of the oversight panel are acknowledged on the title 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

PAVEMENT MANAGEMENT APPLICATIONS USING GEOGRAPHIC INFORMATION SYSTEMS

SUMMARY

This synthesis documents the state of the practice and knowledge of pavement management applications using Geographic Information Systems (GIS) and other spatial technologies. Pavement management systems (PMS) are supported by collecting and retaining a large amount of information that is normally available in a wide variety of formats, referencing systems, and media. GIS and other spatial data management and analysis technologies are particularly appropriate for integrating, managing, collecting, cleaning, analyzing, and presenting these data. This synthesis introduces PMS, GIS, and spatial analysis and discusses how the technologies have been combined to enhance the highway management process. It reviews the principal issues related to PMS data collection, integration, management, and dissemination; applications of spatial technologies for map generation and PMS spatial analysis; and implementation.

Information for this report has been reviewed and synthesized from a variety of sources, including a literature review, an electronic survey of state practices, and follow-up telephone interviews with a select number of state transportation agencies. The survey of practice was conducted electronically using an interactive web-based survey tool developed by the Kansas Department of Transportation (DOT). The electronic questionnaire was sent to the pavement management contacts and GIS-T (GIS for Transportation) representatives (i.e., two per agency) from all 50 state DOTs, as well as to some Canadian provinces. A total of 73 responses, from 48 states and 4 Canadian provinces, was received.

PMS have become standard tools in most state DOTs because highway agencies have realized the benefits of having a decision support system that assists them in finding cost-effective strategies for managing their pavement networks. Pavement management is a business process that allows DOT personnel to make cost-effective decisions regarding providing, evaluating, and maintaining pavements in a serviceable condition. A PMS provides tools and methods to support these decisions by answering questions such as *what* general maintenance and rehabilitation strategies would be the most cost-effective, *where* (what pavement sections) maintenance and rehabilitation treatments are needed, and *when* would be the best time (condition) to program a treatment. Furthermore, there is a trend toward the development of management systems for other transportation assets and the integration of the decision support tools in comprehensive asset management systems. PMS are one of the key components of asset management not only because they provided the framework for their development but also because they are the main business process and account for up to 60% of the total assets in a typical DOT.

Spatial analysis technologies, such as GIS, spatially enabled database management systems, and middleware applications, provide effective means for developing PMS tools. The field of spatial analysis has grown significantly in recent years, thanks to the introduction of a relatively inexpensive and relatively easy-to-use GIS. More recently, other spatially enabled databases and software components have been developed specifically for highway management. These software components or “middleware” sit between the database that resides on a server computer and the end-user applications and provide many of the functions and procedures that an end-user application requires. A GIS consists of computer hardware, software, personnel, organizations, and business processes designed to support the capture, manage-

ment, manipulation, analysis, modeling, and display of spatially referenced data for solving complex planning and management problems. A comprehensive GIS includes procedures for data input, either from maps, aerial photographs, satellites, surveys or other sources; data storage, retrieval, and querying; data transformation, analysis, and modeling; and output generation, including maps, reports, and plans. For the purpose of this synthesis, the concept of a GIS is discussed as a "process" for integrating spatial data into the decision-making process rather than as specific GIS technologies or software packages.

The review of practice conducted showed that most DOTs are either currently using or are planning to use GIS or other spatial technologies to support pavement management activities, because enhanced spatial capabilities for data storage, integration, management, and analysis augment many of the PMS functions. For example, GIS and other spatial tools can facilitate the following PMS problems: output presentation, data collection and processing, data integration, and incorporation of spatial data into the PMS analysis.

Current state of the practice includes the use of spatial tools for map generation and, to a lesser degree, database integration. A GIS is used primarily for preparing multicolored maps and graphic displays of information, such as pavement conditions and construction schedules. Spatial technologies are also increasingly being used for data collection, cleaning, integration, and maintenance. Although spatial analysis tools and technologies allow for more advanced analysis, only a very limited number of states are currently using these tools as part of the decision-making process. Planned activities show a trend toward the use of more advanced GIS capabilities, such as data integration and spatial analysis.

Data collection activities are one of the key aspects of the pavement management process. The principal data collected for a PMS include road inventory, pavement structural and functional conditions, traffic (volume and weights), and maintenance and rehabilitation history. In most DOTs, at least some of the data used by the PMS is collected and maintained by a section or division other than the PMS, thus requiring data to be integrated for decision support. In addition, automated data collection equipment is used to acquire at least part of the inventory and condition data. Although all of the agencies surveyed use linear referencing systems for their PMS data collection and storage, coordinate-based systems are also becoming popular. Approximately one-half of the DOTs use global positioning systems (GPS) in at least part of their data collection activities. The use of GPS has many advantages in terms of location accuracy and data integration potential; however, it also creates a significant challenge regarding compatibility with historical data and interoperability with existing systems.

Spatial database management systems, such as those included in a GIS and other tools, are very useful for facilitating the integration of data with graphic information and with different data sets. Pavement management decisions require information from a variety of sources, information that has generally been kept in separate databases and is often managed by different sections within the DOT. Because all PMS data can be related by its spatial location, spatial tools such as GIS are particularly appropriate for their integration. Enterprise-wide data integration is also very important as agencies move toward more global asset management approaches to manage different types of transportation assets. However, the number of agencies that have actually completed, or are close to completing, a full integration of their various highway management systems is limited. Most respondents to the survey indicated that they agree or strongly agree that spatial applications may facilitate integrating PMS with wider asset management initiatives. A series of examples of data integration efforts among DOTs is presented in this synthesis report.

In addition to supporting data collection and integration, spatial tools have been used to support PMS analysis and reporting functions. At its most simple level of use, a GIS is a powerful and efficient tool for generating colored maps and graphical displays that may depict road conditions, work programs, and maintenance schedules, among many other applications. This type of application is very valuable, but it can also be performed by other automated mapping tools that can only conduct analyses using a linear referencing system and that do not use the enhanced topological and spatial data-handling capabilities of a GIS.

State DOTs have also started to take advantage of spatial analysis tools and technologies to develop more advanced PMS applications. Example applications include performance prediction by jurisdiction, geographic integration of sections into projects, and resource allocation among districts or regions. Many GIS packages and highway management spatial tools have incorporated the spatial modeling capabilities and functionality necessary for conducting these types of analyses. However, only a very limited number of states are currently using spatial analysis tools as part of the PMS decision-making process.

There are several spatial and mapping technologies and tools available to support the development and enhancement of PMS, including automatic mapping tools, GIS packages in the traditional sense, data management systems with enabled spatial capabilities, and middleware applications developed to support highway and asset management. In general, users are satisfied or neutral with respect to the user friendliness, learning curve, technical support, flexibility, and functionality of their spatial packages.

The spatial applications that have been developed to support a PMS range from simple interfaces with which to input and output data to and from a GIS to sophisticated models that take advantage of advanced spatial analysis capabilities. Implementation of the spatial or GIS-based tools has been approached as an individual effort by the PMS group or as an agency-wide cooperative effort. The GIS implementation as an agency-wide effort appears to be more effective because the costs associated with the development and maintenance of the georeferenced base maps are high and the information in the GIS is used to support other areas and functions within the DOT.

One of the main questions about the implementation of spatial tools for a PMS is whether the benefits will outweigh the costs of developing the tools and implementing the GIS database. The DOTs that have developed spatial tools for a PMS generally agree that it is cost-effective. Studies of the cost and benefits of implementing GIS-T as an agency-wide effort in Florida and Illinois indicate that in the long term (after approximately 5 to 7 years) the estimated efficiency and effectiveness benefits clearly outweighed the cost.

The principal problems identified with the development and use of spatial (e.g., GIS-based) PMS applications are related to the use of different referencing methods, the level of effort required to develop and maintain the spatial-enabled databases, and the handling of temporal issues. Other reported problems included differences among users in the level of detail required to describe the network, accuracy of GPS-collected data when real-time differential correction is not available, excessive user expectations, and the steep learning curve required for users to be able to understand and use the GIS software and procedures. Many of the problems identified relate more to database design and connectivity and PMS application development than to the spatial technologies used.

The main improvements that were suggested by the DOTs for facilitating the use of spatial technologies to develop PMS tools included (1) better automatic procedures to facilitate the integration and resolution of data collected and stored using different location-referencing systems, (2) enhanced map-matching techniques, and (3) incorporation of temporal dimension. These enhancements will not only improve a PMS but will also help advance data quality and accessibility throughout the organization, thus streamlining the work processes.

CHAPTER ONE

INTRODUCTION

This chapter introduces the basic problem associated with the use of spatial data management and analysis procedures for pavement management. It also presents the objective, scope, and organization of the synthesis report.

BACKGROUND

Pavement management systems (PMSs) have become standard tools in most state departments of transportation (DOTs). Highway agencies have realized the benefits of having a decision support system (DSS) that assists them in finding cost-effective strategies for managing their pavement networks (*1*). Furthermore, there is a trend toward the development of management systems for other transportation assets and the integration of the decision support tools in comprehensive asset management systems. This trend was furthered by the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 (*2*), which required state DOTs to develop several management systems that had to be integrated with one another to a certain degree. Although some of the penalties associated with this mandate were later removed, many DOTs realized the advantages of such an approach and continued the efforts toward developing the management systems and integrating them in agency-wide asset management systems. Furthermore, the *Governmental Accounting Standards Board Statement 34: Basic Financial Statements—and Management's Discussion and Analysis—for State and Local Governments*, reenergized this trend by specifying that full accrual accounting principles be used for government-wide statements. This standard allows agencies to use a modified or preservation approach that does not depreciate physical assets (e.g., roads and bridges) that are maintained at a level predefined by the government. However, to use this reporting method, agencies must have in place appropriate asset inventory, condition assessment and monitoring, and preservation procedures that are characteristic of pavement and asset management systems (*3*).

Pavement and asset management systems are supported by collecting and retaining a tremendous amount of information associated with the nationwide network of highways. Agencies collect and store data from a variety of sources, such as historical records, surveys, and automated data collection vehicles. A PMS uses road inventory, pavement condition, traffic, and construction and maintenance history data that are not always collected by the same office within the organization. These data are normally available in a wide variety of formats, spatial and database referencing systems, and media. Examples include drawings, pictures, maps, text descriptions, tables, video, and experience. Integrating data to support decision making requires that the data be stored by using consistent indexing, location referencing systems, and data definitions or that appropriate transformations be developed.

Transportation agencies must organize the data available for pavement and asset decisions into forms suitable for many applications at the different levels of decision making within the agency. Examples include investment tradeoffs among different asset types; highway monitoring and management; development of construction, maintenance, and rehabilitation programs; and design and analysis of specific projects. Consequently, there is a demand for efficient tools for integrating, managing, and analyzing that information.

Spatial technologies, such as Geographic Information Systems (GIS), are particularly appropriate for integrating highway data and enhancing the use and presentation of these data for highway management and operation by using spatial relationships to relate geographic and geometric objects and events. To different degrees, highway management problems, such as pavement management, involve relations between objects and events located in different spatial positions. Road networks extend over a wide area and interact with various land elements, including rivers, mountains, buildings, and other roads. Because the data used in the decision-making process have spatial components, the use of spatial technologies emerges as a very appealing alternative. Spatial technologies may enhance the analysis of several transportation-related issues and may improve the quality of the decision-making process.

SYNTHESIS OBJECTIVE AND SCOPE

There are a number of states that have developed, or are developing, spatial applications for pavement management. The objective of this synthesis is to systematically document the state of the practice and knowledge of pavement management applications using GIS and other spatial technologies. The main points addressed include the identification of best practices, potential future applications, and the spatial analysis features that are needed for developing more powerful and effective PMS applications.

Synthesis Scope

Although this synthesis discusses issues regarding the use of different spatial referencing methods, its focus is on the application of GIS in pavement management. It includes information from a number of sources, including a literature review, an electronic survey of state practices, and follow-up telephone interviews with a select number of state transportation agencies. The survey was conducted electronically using an interactive web-based survey developed by the Kansas DOT (KDOT). A link to the electronic survey was sent to the pavement management contacts and GIS-T (GIS for Transportation) representatives in all 50 states as well as some Canadian provinces. The surveyed individuals were asked to go to a web page where an electronic questionnaire was displayed. This questionnaire was dynamic and the questions displayed were dependent on the previous responses. Once the user pressed the submit button, the survey was automatically saved in a database and a "special link" was e-mailed to the respondent. This link allowed the respondent to return to the response and review, complement, or modify the submitted information. After the survey stop date, KDOT PMS personnel imported the responses into an MS Excel spreadsheet and transmitted it to the consultants.

The electronic survey proved very effective, with a total of 73 responses from 48 states and 4 Canadian provinces received. Many respondents indicated that the web-based format made it very easy to respond to and submit the questionnaire. For the purpose of the statistical analysis, and to avoid double counting, only one response per state was considered. In a few cases, the responses from the PMS and GIS-T representatives did not agree. These inconsistencies showed that, in several DOTs, the GIS-related activities are perceived differently by the two groups and that there is a possible communication problem between the PMS and GIS units, as will be discussed further in chapter two. The differences were resolved through follow-up telephone interviews. The PMS contact response was used when available, except for the sections that dealt with system integration and software use.

Report Organization

Chapter two includes a brief introduction to PMS, GIS, and spatial analysis, and discusses how the technologies have been combined to enhance the highway management process.

Chapter three covers the primary issues related to PMS data collection, management, and dissemination. The main sources of pavement management information are identified. Issues pertaining to the type of data collected, data storage, methods of referencing, interaction with other management systems, data integration, and the handling of historical records are discussed. Examples of spatial application for PMS data integration are presented.

Chapter four presents some of the main applications of spatial technologies for map generation and PMS spatial analysis.

Chapter five covers the approaches used for integrating PMS and GIS, the different GIS tools used to support pavement management decisions, and other implementation-related issues. The level of satisfaction, advantages, problems, and solutions are discussed.

Chapter six summarizes the main findings of the research and the major conclusion of the synthesis study. This chapter also provides some recommendations for future research needs.

CHAPTER TWO

PAVEMENT MANAGEMENT SYSTEMS AND SPATIAL ANALYSIS TECHNOLOGIES

This chapter includes a brief introduction to PMS, GIS, and spatial analysis, and discusses how the technologies have been combined to enhance the highway management process.

PAVEMENT MANAGEMENT SYSTEMS

There are more than 6 million km (approximately 4 million mi) of public roads in the United States, of which approximately 64% are paved. Pavement management is a business process that allows DOT personnel to make cost-effective decisions regarding the pavements under their jurisdiction. Two AASHTO documents provide a complete treatment of pavement management and PMS, including objectives, components, and benefits. The *Guidelines for Pavement Management Systems,* published in 1990, provides the basic information needed to develop a framework for PMS (*1*). The 2001 *Pavement Management Guide* discusses in detail the technologies and processes used for the selection, collection, reporting, management, and analysis of data used in pavement management at the state level (*4*). Extensive information about the development, implementation, and use of PMS by towns, cities, and counties can be found in National Highway Institute (NHI) course 13426, *Road Surface Management for Local Governments* (*5*). Although in its broadest definition pavement management covers all phases of pavement planning, programming, analysis, design, construction, and research (*6*), most implemented PMS are restricted to addressing pavement maintenance and rehabilitation (M&R) needs (*4*). PMS assist in providing answers to the following questions (*1*):

- What general M&R strategies would be the most cost-effective?
- Where (what pavement sections) are M&R treatments needed?
- When would be the best time (condition) to program a treatment?

Because of increasing system and budget demands, more public accountability, and limited personnel resources, and in particular the GASB (Governmental Accounting Standards Board) 34 accounting procedures, state DOTs are changing their way of doing business and embracing an asset management business approach (*7*). Asset management is the term commonly used by business to describe the systematic process of maintaining, upgrading, and operating physical assets cost-effectively, efficiently, and comprehensively (*8*). Under the leadership of the FHWA, state DOTs have realized the benefits of this approach and are starting to reengineer their business processes accordingly. Many agencies have focused attention on asset inventory and condition data integration, in many cases using a GIS for data integration, and are working on integrating management decisions of existing "stovepipe" management systems—such as PMS and bridge management systems—for executive-level decisions (*7*). In addition, there is a trend toward supplementing subjective policy-based decision making with objective, performance-oriented tools. PMS are one of the key components of asset management, not only because they provided the framework for their development, but also because they are the main business process and account for up to 60% of the total assets in a typical DOT.

A PMS has been defined as a "set of tools or methods that can assist decision makers in finding cost-effective strategies for providing, evaluating, and maintaining pavement in a serviceable condition" (*1*). A PMS provides a systematic process for collecting, managing, analyzing, and summarizing pavement information to support the selection and implementation of cost-effective pavement construction, rehabilitation, and maintenance programs (*2*). To effectively support these types of decisions, a PMS must include reliable and sufficient data; calibrated analysis models and procedures; and effective, easy-to-use tools that help visualize and quantify the impact of the possible solutions considered.

Although the approaches used by agencies differ, the foundation of all PMS is a database that includes the following four general types of data:

1. Inventory (including pavement structure, geometrics, and environment, among others);
2. Road usage [traffic volume and loading, usually measured in equivalent single-axle loads (ESALs)];
3. Pavement condition (ride quality, surface distresses, friction, and/or structural capacity); and
4. Pavement construction, maintenance, and rehabilitation history.

Figure 1 shows the percentage of the responding states and provinces that collected or used each of these specific data elements. It was surprising that not all the agencies reported that they are collecting inventory data, because

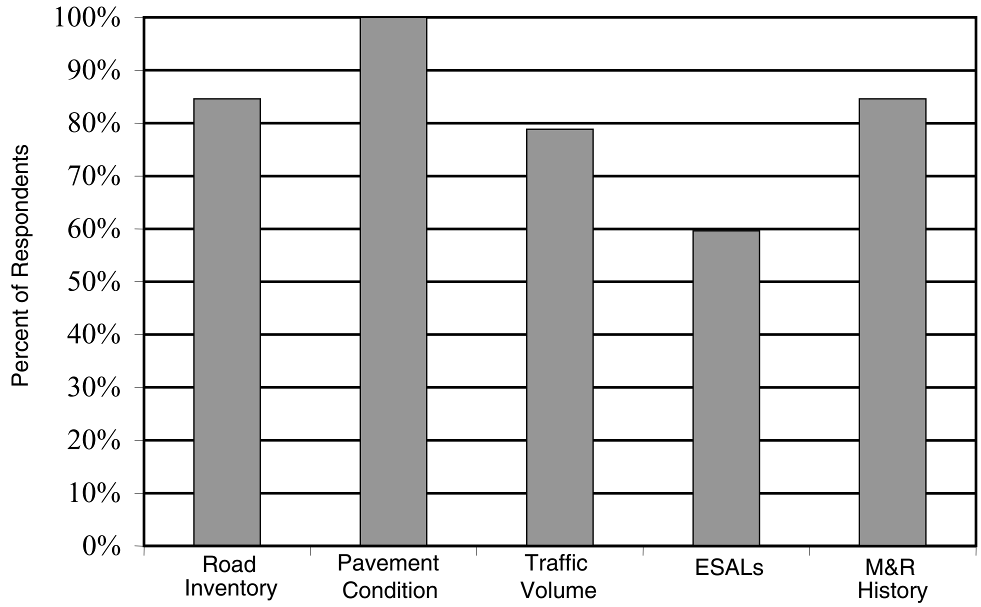

FIGURE 1 Types of pavement management data collected.

these data are necessary for supporting the other data collection activities. However, this may be because the responsibility for collecting inventory data often does not reside with the PMS office.

PMS analysis capabilities include network-level and project-level tools. "Network-level" analysis tools support planning and programming decisions for the entire network or system. A PMS usually includes tools to

- Evaluate the condition of the pavement network and predict pavement performance over time;
- Identify appropriate M&R projects;
- Evaluate the different alternatives to determine the network needs;
- Prioritize or optimize the allocation of resources to generate plans, programs, and budgets; and
- Assess the impact of the funding decisions.

"Project-level" analysis tools are then used to select the final alternatives and to design the projects included in the work program. The pavement management cycle then continues with the execution of the specified work. Changes in the pavement as a result of the work conducted, as well as normal deterioration, are periodically monitored and fed back into the system. From an asset management perspective, the network-level goals and available budgets are defined by higher-level strategic decisions that set the overall goals for system performance and agency policies. PMS produce reports and graphic displays that are tailored to different organizational levels of management and executive levels, as well to the public (*9*).

Enhanced spatial capabilities for data storage, management, and analysis augment many of the aforementioned functions and tools. For example, GIS and other spatial tools can facilitate the following PMS functions:

- Data collection and processing—GIS and global positioning systems (GPS) could allow collecting data using a coordinate-based method and relate the information to the base highway network. The display of inventory and condition data on color-coded maps may also facilitate data cleaning and gap detection. These maps can highlight contradictory or redundant information as well as sections with missing data.
- Data integration—The use of database management tools that can handle spatial data can facilitate the integration of the data used for supporting PMS decisions—inventory, pavement condition, traffic, and maintenance history—and is collected or stored in different DOT units.
- Incorporation of spatial data into the PMS analysis—Spatial GIS tools allow users to efficiently overlay point and area data, which is not route specific, with the linear road network for PMS modeling. Examples include the use of weather or regional information in the development of pavement performance models, the computation of average treatment cost by district or region, or the use of land use and regional development models for enhancing traffic predictions. Spatial analysis tools can also facilitate grouping projects based on geographic proximity or other criteria to obtain economies of scale or reductions in traffic disturbances.

- Output presentation—The user can easily generate color-coded maps and graphic displays depicting road conditions, coverage of evaluation campaigns, and maintenance and rehabilitation schedules, among many other applications. GIS can also facilitate the computation of statistics by areas or regions; for example, the average condition of the roads by county. These maps are an integral part of condition reports and work programs usually generated by the DOTs.

It is for these reasons that many agencies have used, or are actively pursuing the use of, GIS and other spatial technologies for developing PMS applications. According to the survey of practice conducted for the preparation of this synthesis, 31 agencies (60%) reported that they are currently using spatial applications for PMS and 14 agencies (27%) indicated that they are not. An additional seven agencies (13%) provided conflicting information; although the PMS respondent indicated that spatial tools were not used or was unsure if they were used, the GIS representative indicated that the PMS did used spatial tools. The discrepancies were resolved through follow-up telephone calls that revealed that although a GIS is not used to support PMS decisions, it is used to prepare maps and displays. Furthermore, seven of the agencies (50%) that are not currently using spatial applications for PMS indicated that they have plans for their use.

In addition to indicating if they were using spatial tools to support PMS activities, the survey asked each respondent to indicate the primary current and planned uses of GIS and other spatial applications. The responses to these questions are summarized in Figure 2. Almost all DOTs currently using these technologies (28) use them to prepare maps, and approximately half (15) use spatial database management tools to help them with data integration. A very limited number of respondents (5) indicated that they are using some of the spatial analysis capabilities. However, the planned activities show a trend toward the use of the more advanced capabilities, such as data integration and spatial analysis.

SPATIAL ANALYSIS TECHNOLOGIES

Spatial analysis is broadly defined as a "set of methods useful when the data are spatial" (*10*). It consists of a series of transformations, manipulations, and other techniques and methods that can be applied to spatial data to add value to them, support decisions, and reveal patterns and anomalies that may or may not be immediately obvious. Spatial data consist of "geographically referenced features that are described by geographic positions and attributes in an analog and/or computer-readable (digital) form" (*11*). Spatial analysis allows users to create, query, map, and analyze cell-based raster data; to perform integrated raster/vector analysis; to derive new information from existing data; to query information across multiple data layers; and to fully integrate cell-based raster data with traditional vector data sources. NHI course 151039, *Applying Spatial Data Technologies to Transportation Planning* (*12*), provides detailed coverage of the subject.

The field of spatial analysis has grown significantly in recent years, thanks to the introduction of relatively inexpensive and relatively easy-to-use GIS. More recently,

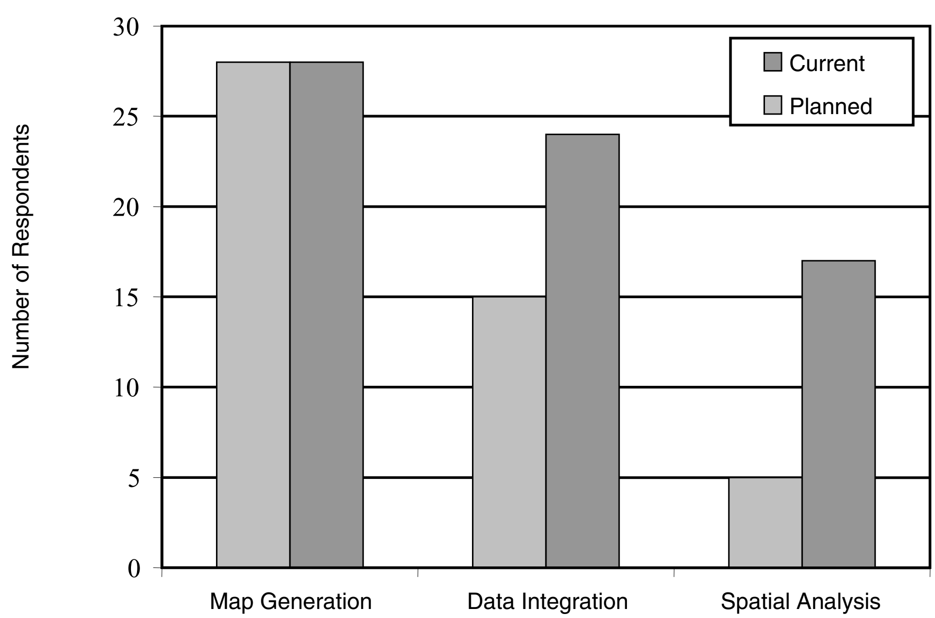

FIGURE 2 Current and planned PMS applications of GIS and other spatial technologies.

other spatially enabled databases and software components have been developed specifically for highway management. These software components, or middleware, sit between the database that resides on a server computer and the end-user applications, and they provide many of the functions and procedures that an end-user application requires. Therefore, such middleware may provide savings in coding and the total cost and effort of building end-user applications in DOTs with respect to the traditional “from the ground up” approach used in the 1960s and 1970s.

GIS

A GIS can be defined as a system of computer hardware, software, personnel, organizations, and business processes designed to support the capture, management, manipulation, analysis, modeling, and display of spatially referenced data for solving complex planning and management problems (*13,14*). Because any definition of a GIS represents a simplistic view of a complex system, the preceding definition is provided only to illustrate the capabilities of the system. Additional definitions, more detailed information, and training materials on GIS can be found in the FHWA *Demonstration Project No. 85: GIS/Video Imagery Applications* (*14*) and NHI course 151029, *Application of Geographic Information Systems for Transportation* (*15*). For the purpose of this synthesis, the concept of a GIS is discussed as a “process” for integrating spatial data into the decision-making process, rather than as specific GIS technologies or software packages.

A comprehensive GIS includes procedures for conducting the following activities:

1. Data input, either from maps, aerial photographs, satellite images, surveys, or other sources;
2. Data storage, retrieval, and querying;
3. Data transformation, analysis, and modeling, and
4. Output generation, including maps, reports, and plans.

GIS link geographic (or spatial) information displayed on maps, such as roadway alignment, with attribute (or tabular) information, such as pavement structure, condition, and age (Figure 3). Although many of the current applications are limited to map generation, a major strength of a GIS is its ability to use topology (i.e., spatial relationships among features) to support decision making for specific projects and/or limited geographic areas. A branch of geometrical mathematics, topology deals with spatial relationships between spatial entities and is concerned with the connectedness, enclosure, adjacency, nestedness, and certain other properties of objects that may not change when the geometry of objects change (*15*). It is in large part what makes GIS different from other spatial technologies; and it is vital to many GIS analysis operations (such as proximity, buffer, overlay, etc.).

A comprehensive GIS includes three important characteristics. First, it includes a database management system (DBMS), which uses georeferences as the primary means of indexing information. This could be the DOT agency DBMS or a GIS vendor-supplied DBMS. Second, a comprehensive GIS integrates spatial analysis functions that incorporate statistical and conceptual models. This feature differentiates a GIS from traditional computer-assisted design/computer-assisted mapping (CAD/CAM) tools. However, recent versions of several CAD programs have incorporated many GIS features. Spatial analysis methods allow

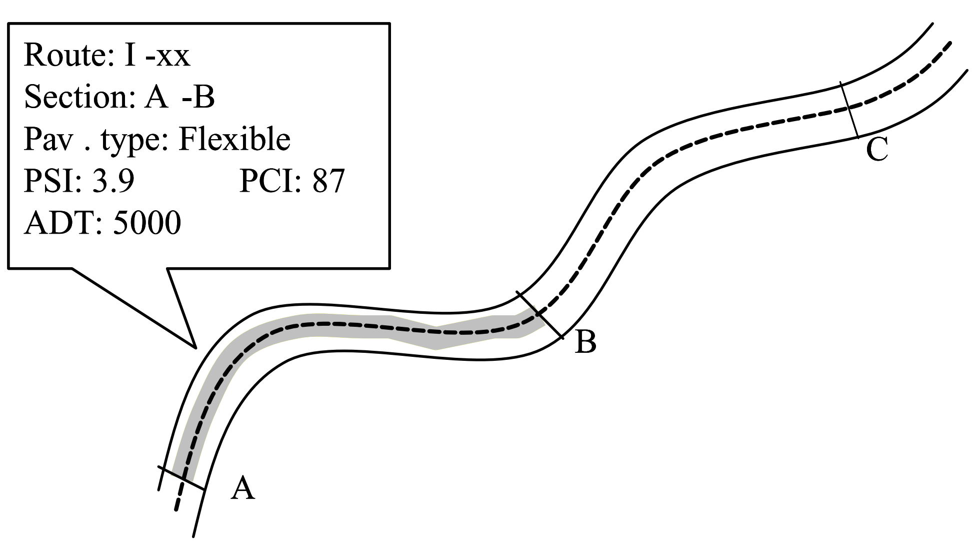

FIGURE 3 GIS functional scheme.

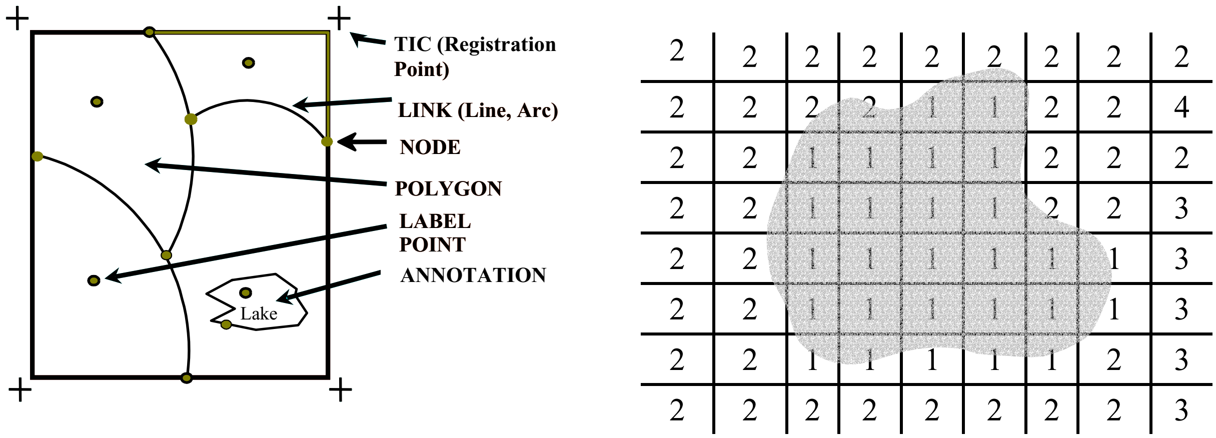

FIGURE 4 Main GIS data structures: (a) Vector data structure; (b) Raster data structure (*15*).

users to perform computations on data groups or layers and to view relationships that would otherwise not be obvious. Third, with its vast array of functions, GIS should be viewed as a process rather than as merely software or hardware. The way in which data are entered, stored, and analyzed using GIS and other spatial tools must mirror the way information will be used for a specific research or decision-making process, such as pavement management.

The manipulation of attribute data is performed by means of a DBMS, which comprises a set of programs that manipulate and maintain the database attributes and geometric objects. Current GIS data structures include raster and vector data structures (Figure 4). Raster data structures are defined by dense arrays of values that represent features requiring large storage capacities and a lower nominal spatial resolution or byte (e.g., digital pictures and satellite images). Processing raster data involves massive element-wise calculations. In contrast, vector data structures are represented by nonuniform, sparse sets of vertices that require less storage by delineating features. Vector data have a higher nominal spatial resolution or byte, but require a complex two-level, arc-node data structure to manage gap-and-overlay problems. Processing involves more complex data manipulations, including numerical integration. Most GIS incorporate both raster and vector functions (*15*).

In vector data, there are three basic geometric or foundational elements that are currently used: points, lines, and polygons. Points are defined by single vertices and are used to represent features such as cities and intersections. Lines are defined by nonclosed sets of vertices and are used to represent linear objects, such as roads and power lines. Polygonal areas or regions (e.g., counties or DOT districts) are defined by closed sets of bounding vertices. For transportation applications, lines or arcs are usually also combined in routes and networks. The choice of data structure depends on what is being analyzed, the application requirements, and the spatial resolution required; most highway management and PMS applications use vector data structures. Most GIS manipulations of spatial elements involve predefined package theory—overlay, split, buffer, and point-in-polygon—that are basically union, intersection, and membership operations that take advantage of the topological relationships between objects. The attributes of a feature describe or characterize the feature.

A GIS can assist in the analysis of many planning and operational problems, such as pavement management, which varies by scale, time, and format, while allowing the enhancement of measurement, mapping, monitoring, and modeling of spatial phenomena. GIS have been used in civil engineering applications for data handling, modeling spatially resident engineering phenomena, and result interpretation and presentation (*16*). Moreover, the ability to efficiently integrate, store, and query spatially referenced data is probably the most compelling reason for using a GIS. Other PMS applications focus on the presentation of analysis results in map form or take advantage of the spatial operations that are included in current GIS software to support many pertinent decision processes.

GIS-T

Current DOT practices are shifting their business processes toward the use of integrated asset management systems for making strategic, agency-wide resource allocations and work programming decisions (*8*). For this reason, there is an increasing demand for means to integrate the great variety of data collected and used by transportation agencies. Given the geographic distribution of the transportation assets, a GIS is one of the technologies of choice for facilitating this process. Many agencies and organizations have supported these developments. AASHTO, along with other agencies, has sponsored annual GIS for Transportation Symposiums that offer forums for persons in government and private industry who are interested in the use of GIS-T

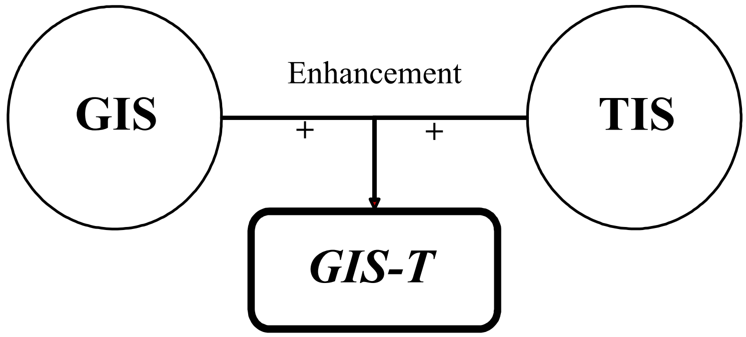

FIGURE 5 GIS-T as the merger of enhanced GIS and enhanced transportation information systems (*18*).

opportunities to gather and share experiences, review state-of-the-art software, and learn more about this field. The proceedings for these symposiums are available electronically (*17*).

NCHRP has sponsored a series of research projects to define the basic structure of a GIS-T. *NCHRP Report 359: Adaptation of Geographic Information Systems for Transportation* (*18*) provided the framework for the adaptation of GIS-T (Figure 5). This project recommended a "corporate" or enterprise-wide approach for information system planning and GIS development within a DOT, as well as a series of GIS enhancements relevant to its application for transportation management and operations. These include enhanced measurement tools; proximity analysis; raster processing; surface modeling; network analysis tools, such as dynamic segmentation and network overlay; and polygon overlay capabilities to link superimposed layers (*18*). Many of these capabilities have since been included in commercial GIS packages, as well as in other specialized highway management tools and database management systems.

NCHRP Project 20-27(2), *Development of System and Application Architectures for Geographic Information Systems in Transportation,* defined a generic information architecture for the implementation of GIS-T and proposed a robust location referencing system data model (*19,20*). Furthermore, because the state DOTs are focusing increasingly on managing the entire life cycle of facilities and coordinating activities with other private and public organizations, there is an increasing focus on referencing the data both spatially and temporally. *NCHRP Report 460: Guidelines for the Implementation of Multimodal Transportation Location Referencing Systems* refined this model to accommodate the elements necessary to use, store, operate, and share multimodal, multidimensional, spatiotemporal transportation data (*21*). The following core functional requirements were identified as needs for an object-oriented location referencing system to support highway management and Intelligent Transportation Systems developments:

- A spatial referencing method that helps locate, place, and position processes, objects, and events in three dimensions to the roadway;
- A temporal referencing system and datum to relate the database to the real world;
- Transformations among linear, nonlinear, and temporal referencing methods without a loss of spatial or temporal accuracy, precision, and resolution;
- Multiple cartographic and spatial topological representations at different levels of generalizations of transportation objects;
- Display and analysis of objects and events at multiple spatial and temporal resolutions;
- Dynamic navigation of objects in near real time;
- Regeneration of objects and network states over time and maintenance of the network event history;
- Association of errors with the spatial temporal data;
- Object-level metadata storage to guide the general user in interpreting the data; and
- Identification of temporal relationships among objects and events or temporal topology.

Several of these functional requirements are important for pavement management. For example, it is important that a roadway segment can be presented as a centerline or as a two-dimensional or three-dimensional spatial object, depending on the scale being used. Similarly, the road segment may be more appropriately represented by a node, link, or polygon for modeling purposes, depending on the application being used. The ability to handle different referencing methods is needed to integrate data collected using different referencing methods. Spatial and temporal considerations are important when considering performance trends, work programming, and life-cycle cost analysis, among other applications.

PAVEMENT MANAGEMENT SYSTEMS' USES OF SPATIAL TECHNOLOGIES

As with any business process, pavement management needs an efficient DSS to be effective. A DSS is a system that provides managers with additional information to help them make better informed decisions as they allocate scarce departmental resources (*22*). This DSS may include procedures and tools for information retrieval and display, filtering and pattern recognition, extrapolation, inference, logical comparison, and complex mathematical modeling. GIS and other spatial technologies can facilitate and enhance the preparation, analysis, presentation, and management of data used for supporting these decisions.

One of the first GIS applications for highway management was the FHWA's National Highway Network database, which was developed using 1:2,000,000 scale U.S. Geological Survey maps (*23*). A PMS was identified early on as one of the areas that could potentially reap great benefits from the use of GIS (*24,25*). After developing a prototype PMS–GIS system, Osman and Hayashi (*26*) identified the following advantages of using GIS for PMS: the possibility of automatically generating maps; enhanced analysis capabilities through powerful spatial queries; enhanced data availability, quality, and integration; and easier consideration of other road assets in the decision process.

There are at least four possible of spatial applications for supporting PMS: map generation and presentation, assisting with data collection, data integration and management, and geospatial analysis. In the early 1990s, Petzold and Freund (*27*) identified two main reasons for a highway agency to have a GIS: map/display and data integration. At its most basic level, a GIS allows data to be visualized quickly in many ways, on both graphic screens and plotted maps. It is possible to zoom in and out on a map display and to show the objects in the database color-coded by grouping or highlighted by selected attributes. A GIS can also be very effective in facilitating the integration of the large amounts of data that are collected and maintained by transportation agencies. A GIS can be a natural way to relate highway databases because they are all spatially related. However, current spatial analysis packages can do more for a transportation agency. They can rapidly answer questions about how data are spatially related or which data have common or related attributes, conduct network analysis, and perform dynamic segmentation, among other features.

Figure 6 shows the status of the integration between GIS and other spatial analysis technologies and pavement management within the agencies surveyed. The respondents were asked to indicate how they would best describe the level of integration between the PMS and GIS tools used. Most agencies indicated that their applications fall in the first category (i.e., the GIS is used mainly for preparing maps and graphic displays). In addition, some agencies are using GIS or other spatial technologies to integrate data and to manage the central enterprise-wide databases. A small percentage of the respondents also indicated that they are using a GIS as the main database for the PMS. It is interesting to note that most available commercial PMS software packages provide GIS interfaces but use other standard DBMS. Only one agency, the Wisconsin DOT, indicated that the spatial tools are fully integrated with their PMS. That PMS was developed using a GIS platform.

The applications are presented in the following chapters: chapter three presents spatial applications for supporting data collection and integration and chapter four reviews applications for map generation and spatial analysis.

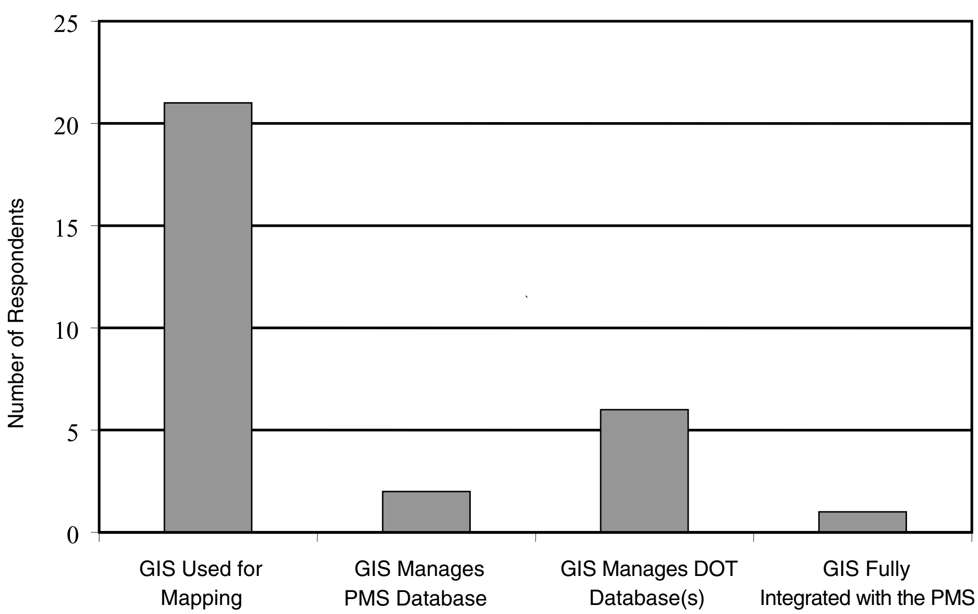

FIGURE 6 Status of the PMS–GIS integration.

CHAPTER THREE

INFORMATION SOURCES AND MANAGEMENT

This chapter covers the main issues related to PMS data collection, management, and dissemination. The main sources of pavement management information are identified. Issues pertaining to the type of data collected, data storage, methods of referencing, interaction with other management systems, data integration, and the handling of historical records are discussed. Examples of spatial application for data integration are presented.

SOURCES OF INFORMATION

Because the decisions made are greatly affected by the available information, data collection activities are one of the key aspects of the pavement management process. According to AASHTO (*4*), there are three basic aspects of this activity: (1) timeliness of collecting, processing, and recording data; (2) accuracy and precision of the data collected; and (3) integration of the data for efficiently supporting decision making. The main data collected for a PMS include road inventory, pavement structural and functional conditions, traffic (volume and weights), and M&R history. The number (and percentage) of agencies that use and collect each of these data elements is presented in Table 1. In many cases, the information is used by the PMS unit but is collected by a different department or division within the DOT. This division has potential problems associated with data integration, accessibility, and location referencing system compatibility. Furthermore, to collect better data efficiently, safely, and economically, most agencies have resorted to the use of automated data collection equipment to collect at least part of their inventory and condition data (Table 1). These vehicles can collect many of the inventory and condition parameters needed for pavement management, and most of them can also collect GPS data. However, integrating the GPS data with data collected and stored using linear referencing methods (e.g., based on route name and linear referencing marking or milepost) is not trivial and usually requires significant processing, as discussed in the following sections. This is the main problem reported with the use of spatial tools for PMS.

DATA STORAGE MEDIA

A PMS uses data from various sources and shares data with other highway management systems. For example, in most DOTs, highway inventory and traffic data are collected by groups that do not deal with pavement management. Fortunately, in most of the cases, the existence of the data in an electronic format facilitates the integration of the data to support pavement management decisions. According to the survey of practice conducted, all the agencies maintain some type of electronic database and only a minority (25%) also maintains paper records. The main database systems used are one independent database, related databases with a consistent referencing method, related databases with different referencing methods, flat files or text files, more than one independent database, and a central enterprise-wide database. Only a small percentage of agencies used data contained in a central enterprise-wide database.

DATA COLLECTION METHODS

Traditionally, DOTs have collected asset inventory and condition information using one of a number of linear referencing methods (e.g., route name and milepost, reference point/offset, or link/node location referencing method). Distance measuring instruments (DMIs) have been used to determine the route's length and the location of physical features along the route. With improvements in GPS technology, DOTs have begun to complement their linear references by collecting data points with GPS. These data points will eventually allow for building reliable baseline reference maps to locate pavement sections and to inventory roadside features with submeter accuracy. Although the

TABLE 1
NUMBER OF DOTs THAT USE AND COLLECT EACH MAJOR PMS DATA TYPE

Item	PMS Uses Data Item?		Collected By PMS?		Data Collection Method: Manual	Auto.	Both	Total
Road Inventory	44	85%	13	25%	14	5	20	39
Pavement Condition	52	100%	43	83%	9	14	28	51
Traffic Volume	41	79%	2	4%	2	14	21	37
ESALs	31	60%	3	6%	6	11	12	29
M&R History	44	85%	26	50%	34	1	8	43

Notes: Auto. = automatic; ESAL = equivalent single-axle load; M&R = maintenance and rehabilitation.
Percentages are based on the number of survey respondents (52).

use of GPS has many potential advantages in terms of location accuracy and data integration potential, it also creates a significant challenge regarding compatibility with historical data and interoperability with existing location referencing methods.

Automated Pavement Data Collection Equipment

Many state agencies are using automated equipment to collect pavement condition data needed for pavement management. A synthesis of state practices is being conducted by NCHRP concurrently with the preparation of this report. Inventory and centerline information is collected using multipurpose, highway, data collection vans that incorporate several of the following technologies: GPS, image capturing using photographic and video (digital) cameras, gyroscopes to determine the longitudinal and transversal slopes, and laser sensors. Pavement condition data acquired include smoothness, surface distress, skid resistance, and structural capacity. Most state DOTs collect pavement smoothness, rut depth, and pavement surface texture using inertial laser-based profilers at the network level. The most common method for measuring pavement friction or skid resistance is the ASTM skid trailer (*28*).

Structural capacity is measured mostly at the project level using falling weight deflectometers (FWDs). However, a few states (e.g., Kansas and Texas) use FWD data at the network level.

A review of best practices in automated highway collection equipment has been prepared by Day et al. (*29*). Roadside assets (e.g., signs and guardrails) inventory can be partially automated using portable computers, personal digital assistants, GPS and voice recognition technologies, as well as specialized equipment that combines these technologies. The Nebraska DOT added a GIS-based application that allows bridge inspectors to have live maps and existing bridge data (including pictures) in a laptop while conducting inspections (*30*).

Referencing Methods

The reference, or indexing, system used by a PMS affects the utility of the system. The data used for PMS are located and stored according to two main methods: (1) using management units (e.g., link/node) or (2) based on a location referencing system. In the first method, the limits of the management units or sections are identified before data collection, and the information is stored by section. This method is simple, but it has problems when section limits change. In addition, it is not very practical when automated data collection is used. The second method consists of collecting data using the referencing method most appropriate for the data being collected (e.g., reference point/offset measured using DMIs for automated pavement evaluation vehicles). This method facilitates automated data collection, but the data has to be linked to a specific management unit or section through some additional processing using a location referencing system (*4*).

A location referencing system consists of techniques for collecting, storing, maintaining, and retrieving location information (*12)*. Highway applications typically use a linear referencing system (LRS), which consists of a set of procedures and a method for specifying a location as a distance, or offset, along a linear feature, from a point with a known location (*15*). Thus, an LRS includes three components: (1) a transportation network composed of lines, (2) a location referencing method, and (3) a datum. The location reference method refers to how to identify a single location in the field. The main domains of location referencing methods include administrative (e.g., county), linear, geodetic/geographic, and public lands survey. Common linear location referencing methods include route/milepost, link-node, reference point/offset, and street address (*12*).

Traditionally, PMS data collection has used linear location referencing methods, such as route name and milepost/logpoint (*4*). In the route name and milepost referencing method, each roadway is given a unique name and/or number, and the distance along the route from a specific origin is used to locate points along the route. The distance units are usually marked with signs placed along the route (e.g., mileposts) to determine the position of linear or point "events" or data collection points in the field. One of the problems associated with this method is that the locations of the signs do not always agree with the actual location of the mile referenced when measuring using a DMI. All of the agencies surveyed indicated are using LRSs. Fifty agencies (96%) use the route/logpoint method and eight agencies (15%) use landmarks for referencing.

However, because of the increased use of GIS, automated data collection equipment, and GPS, coordinate-based referencing methods are becoming popular. The most common coordinate systems are the longitude and latitude, state plane coordinate system, and universal transverse mercator. More than one-third of the agencies surveyed (35%) use longitude and latitude, and a small percentage (13%) use the state plane coordinate or other systems. When more than one referencing method is used, the agencies must establish appropriate transformation procedures to consolidate these reference methods.

GPS Technology

The main issues regarding the collection, processing, and integration of GPS data into GIS were recently summarized in *NCHRP Synthesis of Highway Practice 301: Collecting, Processing, and Integrating GPS Data into GIS* (*31*). GPS is a technology that allows the location of a receiver on the planet to be determined in terms of latitude and longitude with a high degree of accuracy. The technology was first developed for locating nuclear submarines quickly and accurately. There are currently 24 satellites orbiting at 12,600 mi above the earth, which allows a GPS to accurately find a geographic position using trilateration (the measurement of distance and location) of multiple satellites simultaneously. The satellites continuously broadcast a digital radio signal that includes both their position and the time with a precision of one-billionth of a second. Users with GPS receivers can use information from four satellites to calculate their positions on the planet. The receiver compares its own time with the time sent by each satellite and uses the difference between the times to calculate its distance from the satellites.

GPS is currently being used for many applications, including pavement and asset management, vehicle tracking systems, and navigation systems. Initially, the GPS signal was degraded to deny usage by potential military threats. However, this selective availability or signal degradation was ended in May 2000, and users can now obtain 5 to 15 m accuracy or better without relying on differential correction. Furthermore, GPS receivers have been miniaturized to just a few integrated circuits, thus becoming very economical. Compared with manual methods, GPS can help automate and speed GIS data processing and lower costs. It is also less labor intensive and may reduce digitizing and positional errors. Several studies have shown that the cost savings can exceed 50%. For example, the city of Ontario spent $515 and 41 person-hours to inventory 942 fire hydrants using GPS. The same inventory by conventional methods would have cost $4,575 and would have taken 2 to 4 months (*32*). For these reasons, GPS is increasingly being used for facilities inventory and condition assessment. For example, the Virginia DOT (VDOT) has collected centerline information on 60,000 mi of roadway using GPS-equipped mapping vans outfitted with stereo cameras (*33*).

Although GPS accuracy has greatly improved in the last decade, especially after the removal of signal degradation, there are still inherent errors in any GPS-collected point. The accuracy of GPS depends on a variety of factors, including the type of receiver used and the accuracy of its clock. Survey quality receivers can achieve submeter accuracy, whereas recreational units can determine a position to within a few meters. Other factors that can affect the accuracy include the number of available satellites, atmospheric conditions that may slow the time signal from the satellite, and the current geometric constellation of the satellites.

Fortunately, there are several methods for enhancing GPS accuracy, including static and rapid-static GPS, real-time differential correction (RTDC), postprocessing corrections, and map matching. Each method has its advantages and disadvantages, and the most appropriate is normally application specific. Approximately half of the agencies that responded to the survey conducted for the preparation of this synthesis use GPS in at least part of their data collection activities, and several of them use more than one correction technique. Three agencies (12% of the respondents) use static GPS, 16 (64%) use RTDC, 10 (40%) use postprocessing differential correction, and seven (28%) use map matching.

Static and rapid-static GPS provide centimeter accuracy but require that the receiver be positioned in one location for 1 to 2 h or 5 to 20 min, respectively. The higher accuracy is obtained by averaging the signal over a period of time. The GPS user stands at the point of interest, records the coordinates over some time, and the receiver computes the arithmetic average. This average should be close to the true location. This technique is well suited for engineering surveys; however, it is usually not feasible for PMS data collection.

RTDC has been shown to be very useful for dynamic data collection, navigation, and on-the-spot corrected coordinates. RTDC provides a user with fast, convenient, and accurate GPS readings, but it has some additional costs. It requires the user to receive a second signal, in addition to the one from satellites, which is used to calculate and correct the error present in the satellite signal. The second or "correctional" signal usually emanates from a base station. Base stations are GPS receivers located at precisely surveyed locations. By comparing its known location to the GPS-provided location, the base station is able to compute this error and to broadcast it to other GPS receivers. The additional cost of RTDC is because of the required base station. Users can set up their own base station or pay a subscription fee to a company that provides correctional signals. Users must also purchase an additional receiver for the correctional signals or a GPS model with a built-in real-time receiver.

The differential correction can also be done through postprocessing. Postprocessing differential correction allows better position accuracy without the more expensive equipment required for RTDC. The office process is very similar to the real-time application, in that the GPS positions can be differentially corrected based on information collected by a nearby GPS base station. With the advancement of computer and GPS/GIS technology, the differential correction program interface is usually a simple point-and-click operation.

Even using the most accurate data collection techniques, users will need to perform map matching to overlap potentially incongruent GPS-collected data and GIS base maps. Map matching, or conflation, modifies an estimated data collection position by assuming that users are always along road networks. Some of the techniques presented include deterministic, probabilistic, and fuzzy-logic map matching. A detailed description of these techniques and a recommended method are provided in the aforementioned *NCHRP Synthesis of Highway Practice 301* (*31*).

The main advantages of using GPS for PMS data collection include the possibility of determining the location accurately and using standard coordinate systems and reference datum. This makes it easy to import the information into a GIS and may reduce data collection costs, processing costs, and digitizing errors. The use of GPS during data collection may also speed up the data collection efforts, because the operations would not need to stop the vehicle and enter the location into the system. The main disadvantages include the need for specific equipment; potential problems with the signal owing to buildings or heavy foliage attenuating, reflecting, and/or blocking satellite signals; and potential compatibility problems with existing attribute data and maps.

Handling of Historical Data

Another important aspect of data collection and management is the handling of historical data. Two specific issues require detailed attention. The first involves the collection, storage, and handling of periodic pavement usage (traffic counts and weights) and condition data. This information has to be maintained and should be efficiently accessible to support many of the PMS functions, such as determining deterioration trends, evaluating the effectiveness of pavement M&R treatments, and assessing the program's impact on the network performance, among others. This creates potential problems because, although network definition—inventory—is usually updated annually, pavement data changes more dynamically as data collection activities progress throughout the year. The second issue concerning historical data is related to the changes that may occur in the inventory or centerline information because of realignments and other geometric changes. These types of changes create significant problems when dealing with LRSs.

Most of the agencies that responded to the survey (33 or 66%) indicated that their PMS stores sequential temporal records, and the remainder (17 or 34%) indicated that data are replaced with new data and periodically archived. For example, the Illinois DOT conducts historical evaluations using a series of year-end files that are all referenced to a link/node base. The coordinates for all nodes, route system, and attribute data are uploaded monthly (*34*). This allows data tied to the same geographical location to be maintained, even though route naming and milepost numbering conversions may change over time (*4*).

Pavement Information Dissemination

One important aspect of pavement management is the sharing and exchanging of PMS information within different branches of a DOT, as well as with the public. A GIS is particularly useful for presenting visually based information to engineers, planners, and decision makers within the agency, as well as to the public. The graphic representations that can be developed using GIS can help demonstrate the effect of different investment strategies on the overall condition of a pavement network and can show the road segments scheduled for work in a particular district, or the investment per mile by region. Another technology that has become increasingly popular is the Internet; agencies are sharing PMS information internally through their intranets or with the public through the World Wide Web. Forty-five agencies (87%) reported that such information is available upon request, thirty-one (60%) noted that it is available through printed reports, and 15 (29%) indicated that they are using other means of sharing the information. In all, 17 agencies (33% of those surveyed) indicated that their PMS data are Internet accessible, but only one-third of those (10% of the reported applications) are Internet enabled; most of the applications are available through the DOT intranets.

Several agencies share maps displaying pavement condition and scheduled construction projects through the Internet. For example, KDOT currently produces more than 30 pavement management maps per year using GIS, and many of those are available on the Internet (*35*). An example is presented in Figure 7 that depicts the roads within each range of pavement roughness for one district.

DATA INTEGRATION

As previously mentioned, one of the main challenges currently faced by highway agencies is integrating the information necessary for managing their highway networks into a central database or distributed but connected databases. Pavement management data integration is necessary because, in many cases, the information needed to support PMS decision making is available in different units or sections of the DOT. Enterprise-wide integration is very important as agencies move toward more global asset management approaches for managing different types of transportation assets. Data integration has been the subject of a primer prepared by the FHWA (*36*). Additional information can be

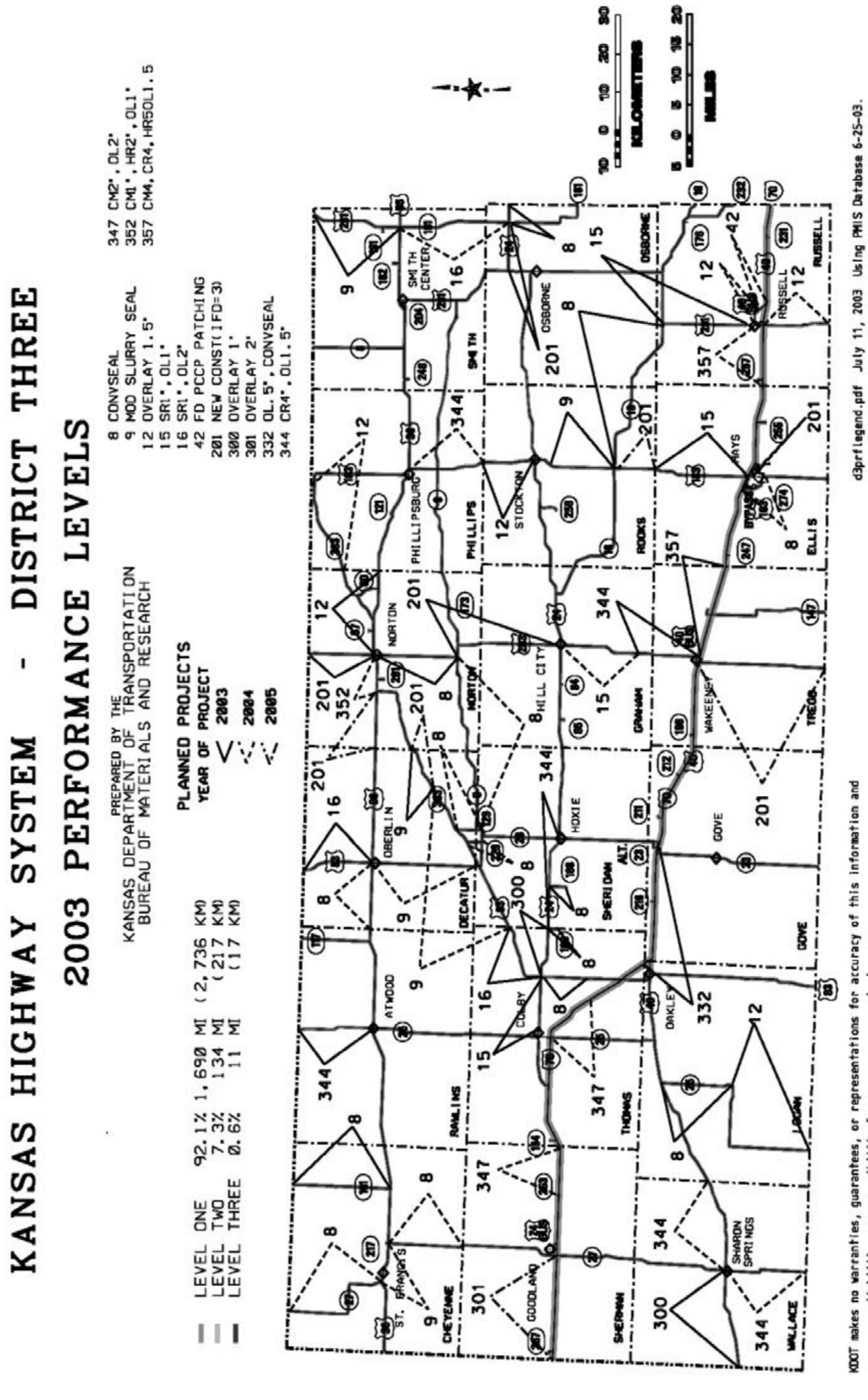

FIGURE 7 Example of pavement condition map.

TABLE 2
MANAGEMENT SYSTEMS THAT CURRENTLY SHARE DATA OR PLAN TO SHARE DATA WITH PMS

Management System	Currently Share Data with PMS*		Plan to Share Data with PMS*	
	Reduced Database	Using all Responses	Reduced Database	Using all Responses
BMS	7 13%	15 29%	16 31%	23 44%
SMS	6 12%	12 23%	8 15%	16 31%
CMS	3 6%	9 17%	4 8%	11 21%
PTMS	1 2%	2 4%	2 4%	6 12%
IMMS	2 4%	4 8%	2 4%	6 12%
MMS	6 12%	11 21%	17 33%	23 44%
AMS	10 19%	5 10%	16 31%	22 42%
Other	4 8%	8 15%	2 4%	4 8%

Notes: BMS = bridge management system; SMS = safety management system; CMS = congestion management system; PTMS = public transportation facilities and equipment management system; IMMS = intermodal transportation facilities management system; MMS = maintenance management system; AMS = asset management system.

*Percentages are computed based on the total number of DOTs that responded to the survey (52).

found in the FHWA's *Demonstration Project 113 Workshop on the Integration of Transportation Information* (*37*).

PMS Data Integration

Pavement management decisions require information (e.g., pavement inventory, condition, usage, treatments, policies, and history) from a variety of sources. This information has generally been kept in separate databases, which are often managed by different sections within the DOT. Because all the PMS data can be related by its spatial location, spatial tools, such as GIS, are particularly appropriate for their integration. However, as previously discussed, issues such as the use of different referencing systems and data formats have presented difficulties for many agencies. The enterprise-wide data integration applications among different management and operation systems are discussed further in the following section. Because the information in the GIS is used to support other areas and functions within the DOT, the development, implementation, and management of the GIS is generally handled by a central office that supports many groups and interests within the agency. In many agencies, the PMS has been one of the first applications of this technology, because it is one of the main—if not the main—core business processes of the DOT. Often, the tools and technologies used in these early applications were not mature and could not provide all the functionality required by the PMS. However, current spatial software provides most of the functions needed for PMS data integration and decision support.

Enterprise-Wide Data Integration

According to the FHWA (*36*), the integration alternatives include two main possible approaches: a fused database and interoperable databases. Database fusion involves a one-time operation to combine data from multiple sources into a single database. Interoperable or federated databases relate data residing in different databases through multidatabase queries. One of the problems with federated databases is the difficulty of maintaining an integrated global model. Although database integration places associated costs and other burdens on an agency, these negative aspects may be outweighed by the long-term benefits. Some of these benefits include the availability and accessibility of the data, enhanced data accuracy integrity, completeness, consistency and clarity, reduced duplication, faster processing and turnaround time, lower data acquisition and storage costs, and integrated decision making (*36*).

Table 2 presents the number of organizations in which the different highway management systems currently share or have plans to share information with a PMS. The table presents the results considering the responses on the reduced database, which was prepared as discussed in chapter one considering the response of the PMS engineers if more than one was available and the number of agencies in which at least one of the responses (*using all responses* from PMS engineers and GIS-T representatives) indicated current or planned integration efforts. The numbers considering all responses are significantly higher than those considering the reduced database, indicating that the pavement management engineers may not be fully aware of all the agencies' data integration efforts. Table 2 also shows that the number of agencies that have actually completed, or are close to completing, a full integration of the systems is limited, at best.

It is relevant to this synthesis that, in many cases, the integration of the data is achieved with the help of a GIS (see Appendix B, Tables B9 and B10). Furthermore, the survey of DOT practice indicated that spatial applications are a key component of the data integration efforts. Most respondents to the survey (41 agencies or 79%) indicated that they agree or strongly agree that spatial applications may facilitate integrating a PMS with wider asset management initiatives, as presented in Figure 8. Although in most cases the different related management systems use the same referencing methods, several agencies use different referencing methods.

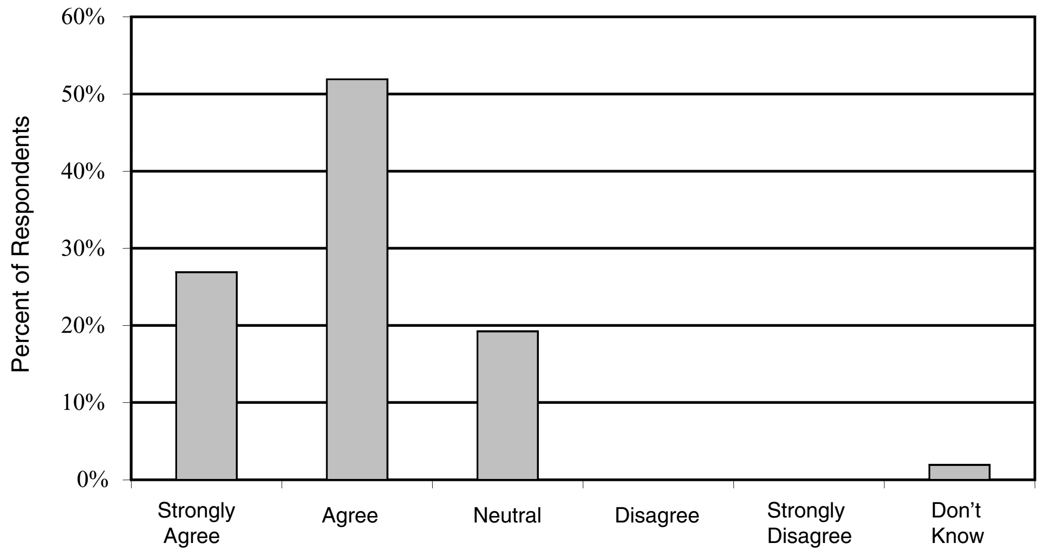

FIGURE 8 Degree of agreement with the statement "Spatial applications facilitate integrating PMS with wider asset management initiatives."

CASE STUDIES

Because of increased demands for better and timelier information for asset management, data integration efforts, and the possibilities offered by the significant information technology advances in the past decade, many agencies are reengineering their databases. Many agencies are migrating from database systems formerly used, such as hierarchical, usually unrelated, mainframe databases, to more flexible, integrated, or interoperable client-server database architectures. In general, these new architectures include spatial and temporal data. A series of examples of data integration efforts among DOTs is presented to illustrate this trend.

The Tennessee DOT developed a GIS that has been used to generate decision maps and related planning information since 1990. Centerline data collected using GPS was linked to the existing Tennessee Road Information Management System mainframe database files and was imported into the agency's GIS. Voice-activated data collection equipment and software were used to update the system's inventory databases (*38*). The system was later enhanced to support pavement and project data (*39*). However, several other forms of highway management data resided in other unsynchronized databases. These data are currently being centralized by an enterprise relational data warehouse that handles both spatial and attributes data using a spatially enabled database and middleware. The system supports GIS clients for internal use and web tools for external users (*40*).

VDOT has for some time used a comprehensive statewide highway mainframe hierarchical database called the Highway Traffic Records Information System (*41*). This database contains the "official" inventory information, which has been corrected over the years. The information in the database is annually imported by the PMS, which also updates the pavement condition. Recently, the DOT has also been developing a GIS-based inventory, condition, and assessment system. Road data were captured using mobile mapping vans equipped with stereo imaging, GPS, and inertial hardware. Centerlines were developed with statewide horizontal accuracy within 2.7 m (*33*). Centerline information (roads layer) was obtained from orthophotos, manual GPS-supported data collection, and GPS-based photologing at 0.01-mi intervals and is being integrated with right-of-way information for the entire highway network, as well as traffic accidents, pavement conditions, and photologs in a central enterprise-wide GIS-enabled database. The system uses a spatially enabled database and middleware and is capable of conducting dynamic segmentation and locating events and objects by coordinates or route and milepost referencing. The milepost is being added as a third dimension, and some centerlines still need to be digitized on the road layer. There are some issues related to incompatible LRSs used at the state and county levels that are being resolved using transformation equations. The GIS information is currently available on VDOT's intranet only (Figure 9), but it will be partially available to the public in the near future. Once the database is complete, the PMS will be one of the users of the spatial information. The PMS will be able to dynamically pull spatial data from the central database and periodically update the pavement-related data.

The Illinois DOT has created a stable roadway link/node base that provides the interfacing mechanism for all roadway-related information. The GIS base includes multiple

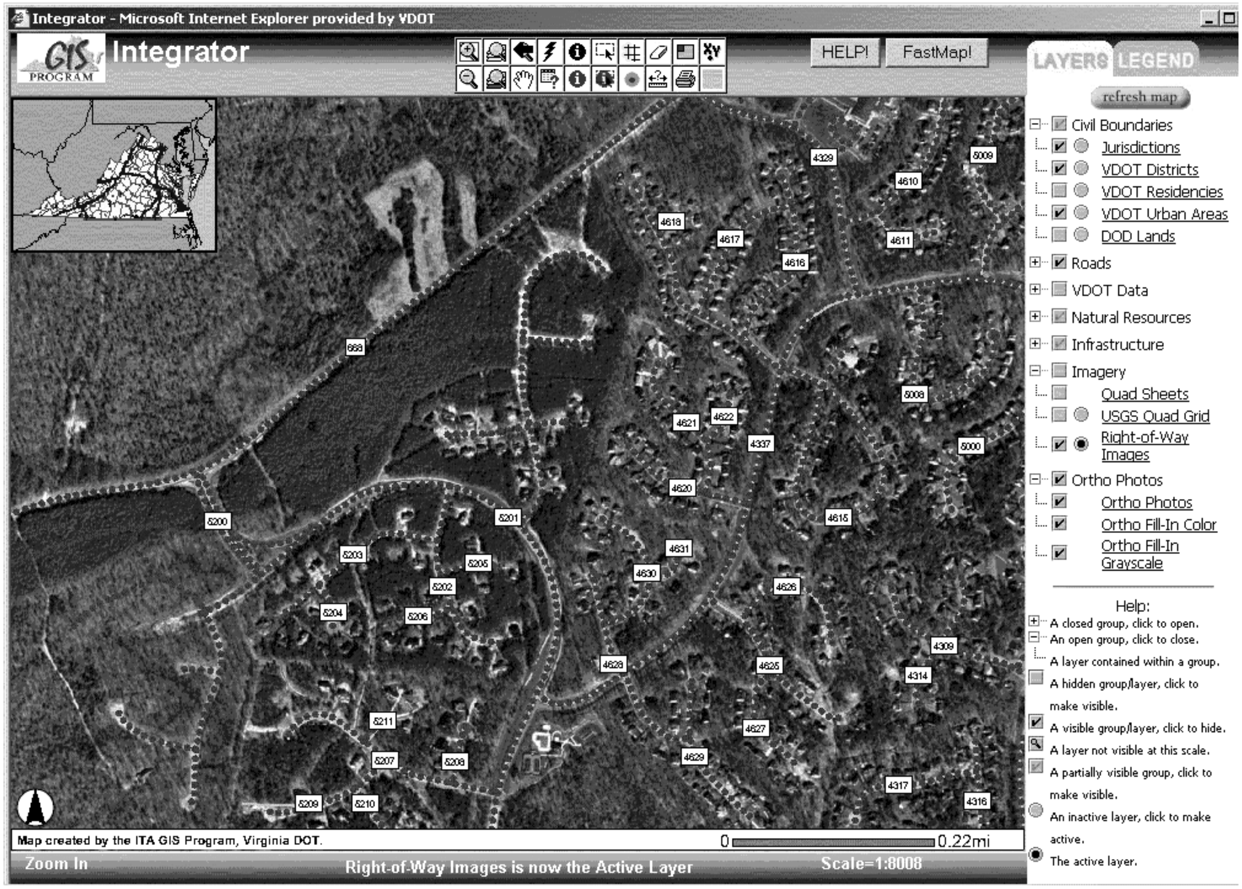

FIGURE 9 Example of web-enabled GIS application displaying the location of right-of-way images superimposed with the roads and orthophotos layers.

references, several route/milepost schemes, various project tracking numbers and structures, and rail crossing identifiers. This GIS development structure enables the department to provide a wide variety of GIS products to a multitude of areas using the same geographic base (*42*). The GIS is used to produce maps, but it is not used to support the PMS decision making.

The Iowa DOT has also integrated many previously unconnected highway databases into a single GIS that allows cross-system data queries and map display. Metadata (data about data) is provided to better define the accuracy and source of the information and to document any significant data updates (*43*). In this case again, the GIS is not currently being used for PMS decision making. Mapping tools are used to create digital maps based on information produced by the PMS. Hans et al. (*44*) discuss the development of a GIS pavement management database to support local governmental agencies and the Iowa DOT's pavement management efforts.

The Ohio DOT integrated several corporate enterprise management systems with its GIS. A total of 11 management systems, including a PMS, were georeferenced. This project not only updated the systems, but also kept them updated as the underlying road networks were modified. The highway network was divided in 0.01-mi intervals. The developed Base Transportation Referencing System includes 11 million records (*45*).

The Florida DOT has developed a GIS-based integrated management system for Metropolitan Dade County to improve the quality of information provided to decision makers and to enhance the statewide and metropolitan planning process. The integrated management system includes six component management systems (pavement, bridge, highway safety, traffic congestion, public transportation facilities and equipment, and intermodal facilities and equipment) and a traffic monitoring system. The predominant use of the DSS is to display information in graphic and report formats to be incorporated into the transportation planning process (*46*).

Some DOTs are also collaborating with other agencies. For example, the Arizona DOT is working with the State Cartographer's Office and the Arizona Geographic Information Council to update and further develop the GIS framework database of Arizona's surface transportation work. The best available network databases, as contributed by the local data owners, are amalgamated by the DOT into a single statewide coverage. This database will eventually be used in the U.S. Census Bureau's roadway feature layer (TIGER) so that other applications will contain the same source data as the locally maintained databases (*47*).

CHAPTER FOUR

DATA ANALYSIS AND PRESENTATION

In addition to supporting data collection and integration, spatial tools have been used to support PMS analysis and reporting functions. This chapter presents some of the main applications of spatial technologies for map generation and PMS spatial analysis.

MAP GENERATION

At its most simple level of use, a GIS is a powerful and efficient tool for generating color-coded maps and graphic displays that may, for example, depict road conditions, work programs, and maintenance schedules, among many other applications. One of the first applications for GIS was its development for display and analysis of the Highway Performance Monitoring System by the FHWA (*27*). The Oak Ridge National Laboratories National Highway Network (*48*) was used as the base map.

This type of application is very valuable, but it can also be done by other automated mapping tools that can only conduct analyses using an LRS and do not use the enhanced topologic and spatial data handling capabilities of a GIS (*49*). CAD and CAM can generate similar maps and are generally easier to use. However, they cannot link the attribute data to the geographical representations and, therefore, the coloring and highlighting of roads with a particular attribute (e.g., scheduled projects or substandard sections) has to be done manually (*4*).

With a GIS application, once the base maps are generated and the attribute data are linked to the geographical objects, it is easy to produce a variety of visual aids by classifying and symbolizing according to specific attributes. These visuals can be of great help in presenting the problems and projected solutions to executive decision makers, planners, and the public in general, using different scales and degree of details. The major types of maps currently used or planned by the agencies surveyed are presented in Figure 10.

Two examples of GIS-generated maps used by VDOT are presented in Figures 11 and 12. VDOT has a PMS only for the Interstate highways and primary roads. Figure 11 shows the percentage of deficient miles on Virginia's roads, color-coded by county, as presented in the 2002 *State of the Pavement Report* (*50*). Currently, only information aggregated by county is displayed on the maps; data on linear spatial features (roads) are summarized by counties manually and are presented on a map using GIS. However, there are plans to display the information segmented by homogeneous sections and construction schedules or linked with the centerline information. Figure 12 shows the graphic display for a prototype web-based application developed by one of the districts, which presents the 2003 paving schedule for the district. Figure 13 is another example of a GIS-generated map; it shows the roadway sections that are above, near, or below a condition threshold established by the Texas DOT for one district.

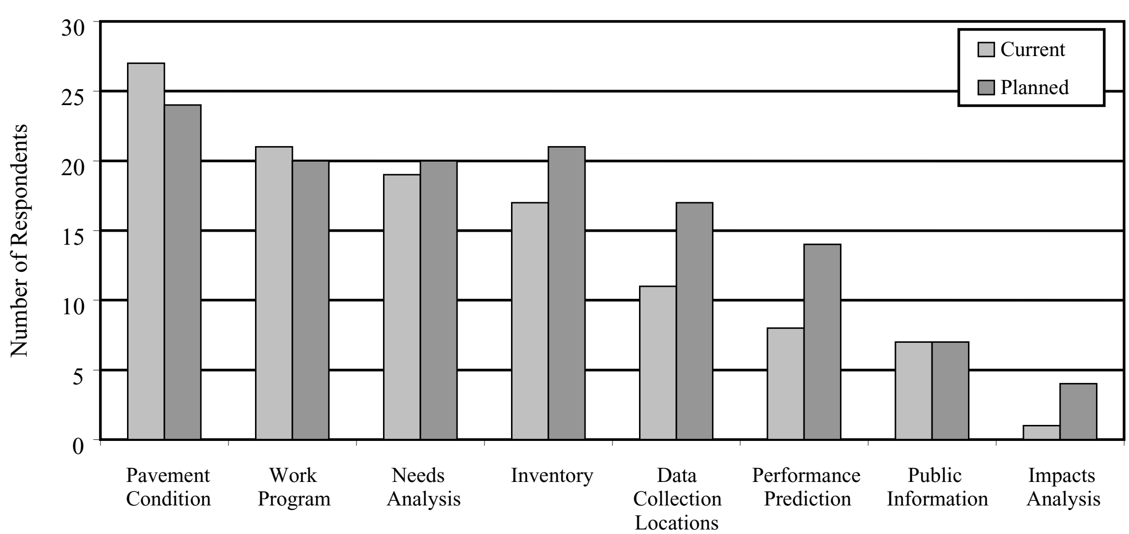

FIGURE 10 GIS-based maps currently used or planned.

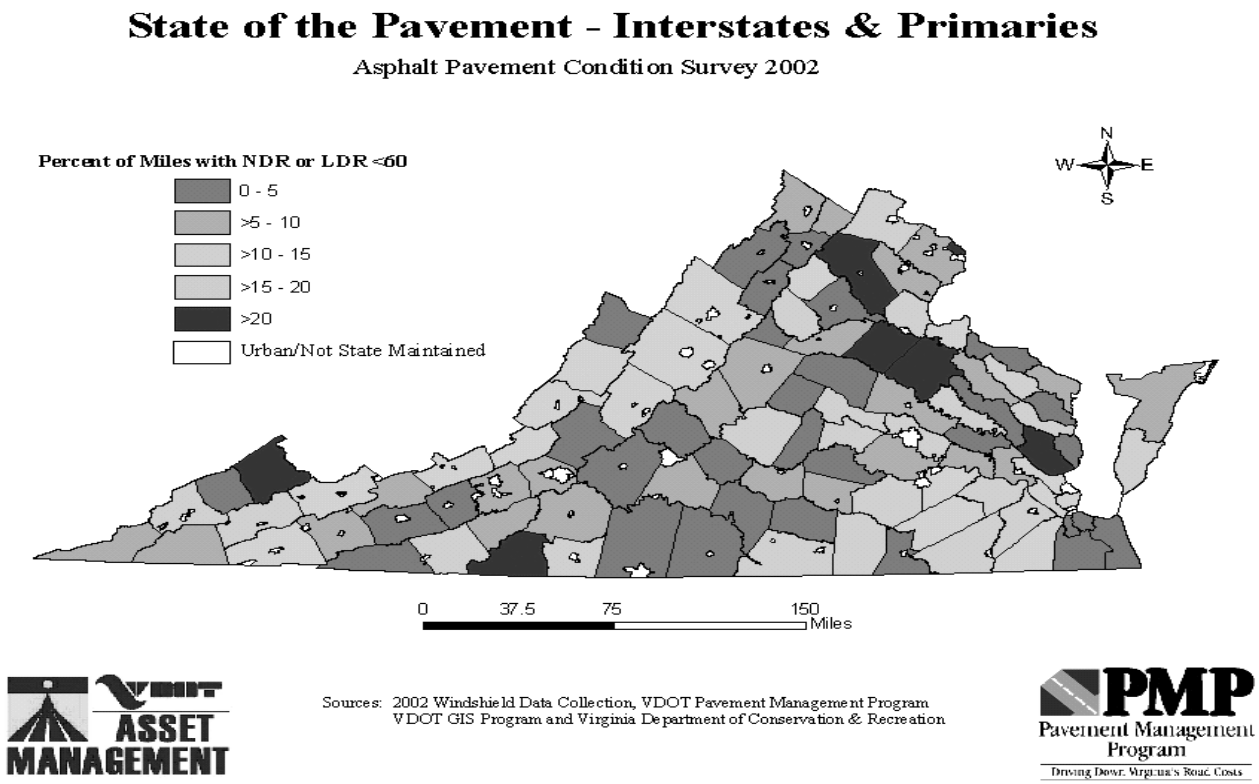

FIGURE 11 Interstate and primary pavement condition by county in Virginia.

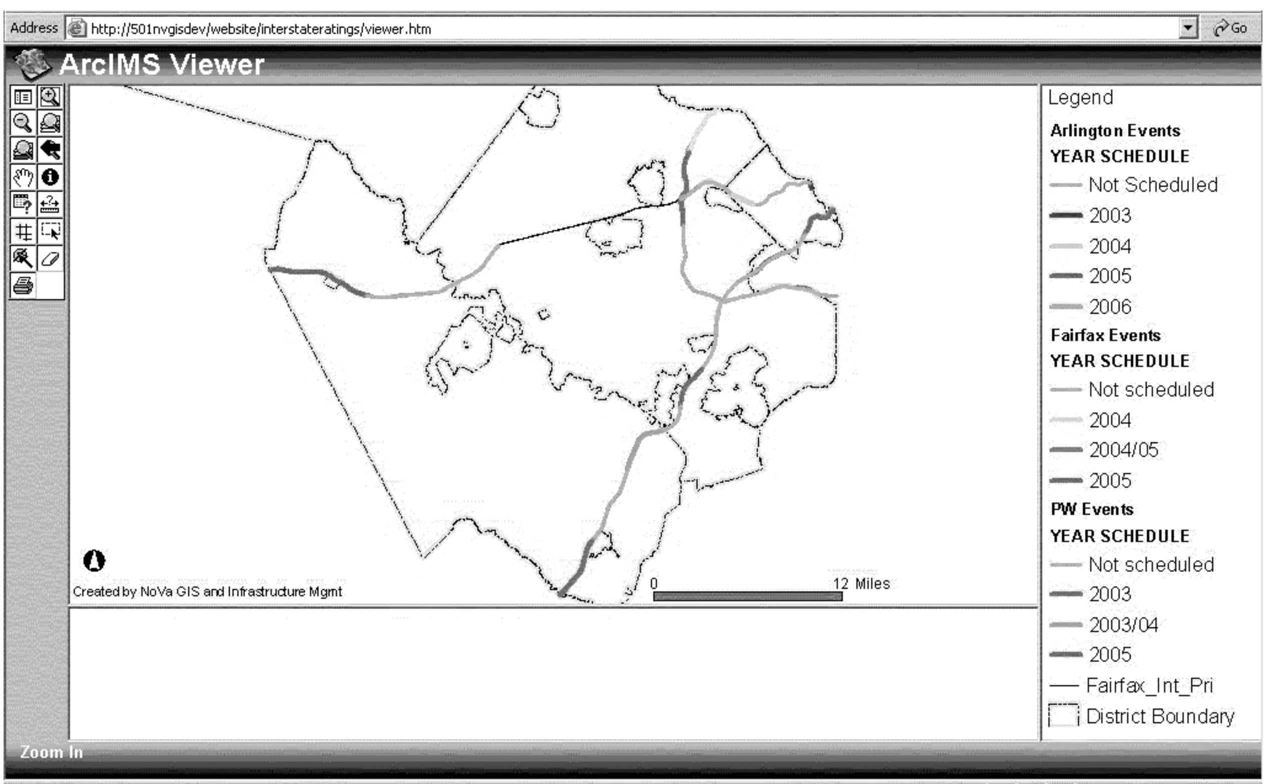

FIGURE 12 Web-based 2003 paving schedule for the NOVA District of the Virginia DOT.

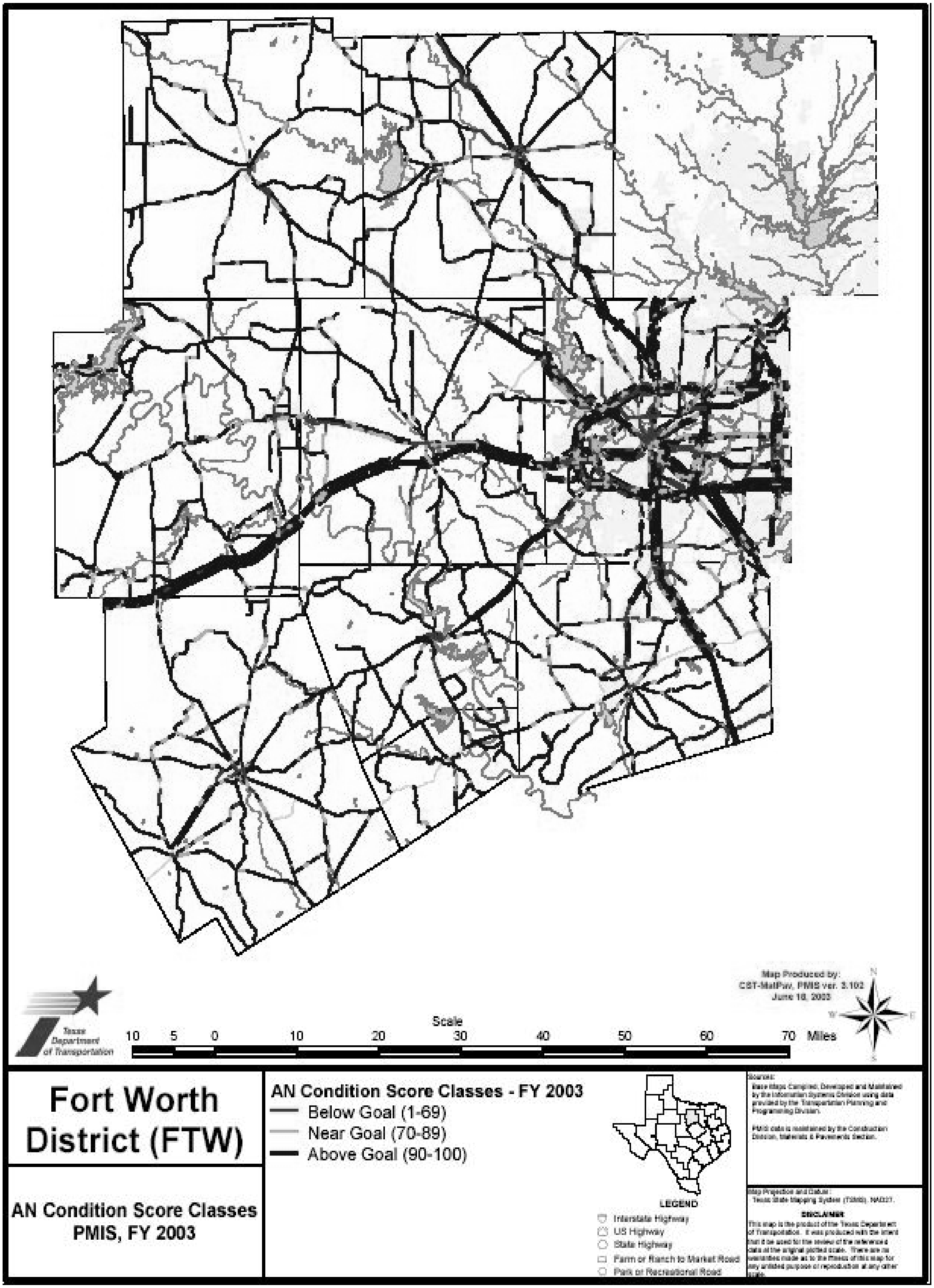

FIGURE 13 Pavement condition score classes for one district of the Texas DOT.

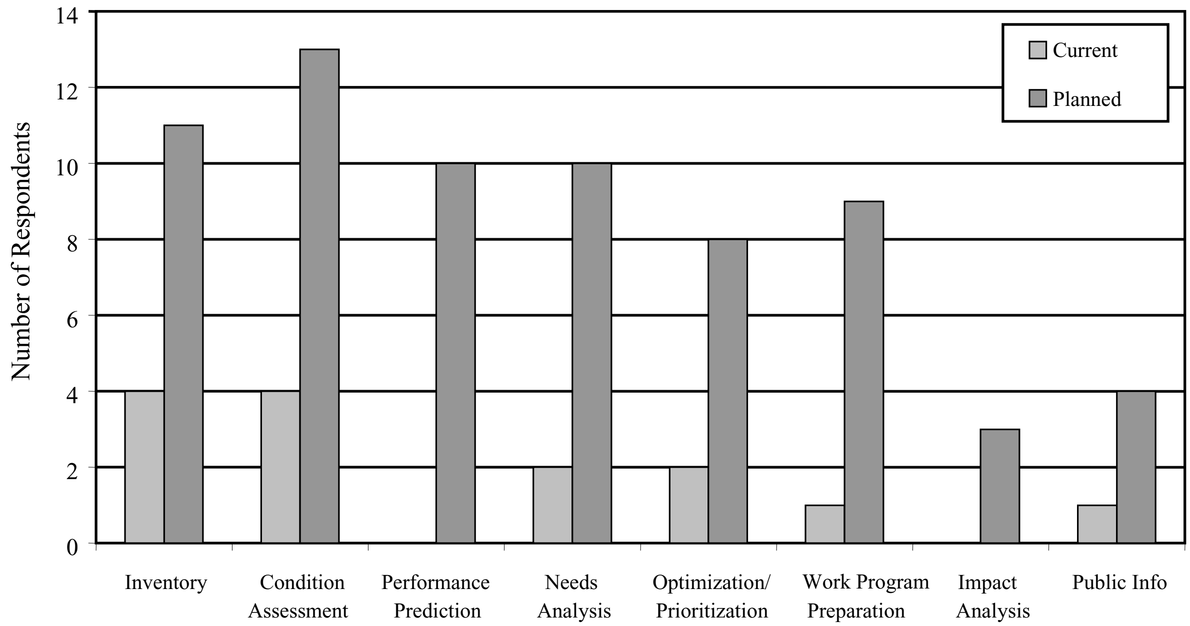

FIGURE 14 Number of agencies that use or are planning to use spatial analysis to support different pavement management functions.

SPATIAL ANALYSIS

Although the areas discussed—data collection, data integration, and map generation—have been a fertile ground for the development of GIS-based PMS applications, the maximum pay-off for the use of the technology may be obtained by taking advantage of its spatial analysis capabilities. Figure 14 shows the number of agencies that use or are planning to use spatial analysis to support the different pavement management functions. Only a very limited number of states are currently using spatial analysis tools as part of the PMS decision-making process, mostly for inventory and condition assessment and, to a lesser degree, for needs analysis and optimization or prioritization of projects. However, there are a significant number of states that are developing or planning PMS tools that use spatial analysis. The main applications include condition assessment, inventory, performance prediction, needs analysis, work program preparation, and project prioritization.

STATE DEPARTMENT OF TRANSPORTATION EXAMPLES

One of the first reported experiences of using GIS for PMS was an FHWA demonstration project conducted by the Wisconsin DOT in which two ongoing efforts to develop a GIS and a PMS were combined. The result was a prototype GIS-based PMS for one of the maintenance districts, which allowed the user to define homogeneous sections, assess pavement performance, identify problems based on that assessment, and recommend pavement improvements for correcting these problems. GIS functions were used to provide dynamic segmentation capabilities to overlap cross sections, performance and improvement sections, and automatic map generation (*51*). The system determines the problems associated with each pavement section [nominal 1.6 km (1 mi) in length] and suggests a range of treatments for repairing all of the problems noted using a rule-based expert system. The pavement sections are then aggregated into improvement (homogeneous) sections, and the final treatment selected is based on five factors: improvement in ride, improvement in distress rating, user inconvenience, initial cost, and life-cycle cost. The projects are then prioritized, and a 6-year improvement program and a 3-year maintenance program are recommended (*52*).

Several other prototype PMS were developed in the mid-1990s. For example, Johnson and Demetsky (*53*) developed a prototype GIS database for pavement management for two counties in Virginia and provided a framework for using a similar approach for other management systems. Osman and Hayashi (*26*) developed a prototype PMS coupled with a GIS composed of a spatial data base, an attribute data base, an analysis module, and an output generation module. Jia and Sarasua (*54*) developed a client/server enterprise-wide GIS, integrated with a Knowledge-Based Expert System by means of a computer network, and they demonstrated its use for a PMS.

The Pennsylvania DOT developed a prototype GIS-based PMS for one engineering district, which has experience in developing long-range plans for resurfacing, roadway widening, surface treatment, and guardrail upgrade programs. Some examples of specific GIS maps developed include roadway inventory, planning compliance, surface improvement, roadway widening, roughness index, long-range improvement program, and crash cluster maps (*55*).

Internationally, highway agencies are following similar paths. The Ministry of Transportation of Spain developed a GIS for highway management that can handle different types of data and different scales. The system allows for the grouping of different types of data, depending on the study to be performed, presenting the data in graphics and maps (*56*). Similarly, the Portuguese highway authority has implemented a PMS that uses a GIS for the generation of some of the input maps (*57*).

With a few exceptions, the applications reported in the literature used the GIS capabilities for map generation only and, in a few cases, for database integration. However, state DOTs have started to take advantage of enhanced spatial analysis capabilities to develop more advanced PMS applications. For example, the Ohio DOT used a GIS to determine whether pavement performance differences exist among the 12 districts. Deterioration trends were developed by transforming existing data into a probabilistic deterioration model using GIS and relational database software (*58*). The Georgia DOT has developed and implemented a client/server and GIS-based pavement management module that seamlessly integrates with the central database where the pavement condition survey data reside. Pavement condition data surveyed by field engineers are uploaded to the central database. The developed system allows managers to visualize statewide pavement conditions in real time and to perform spatial analyses by aggregating information with linear features into different jurisdictions, such as working districts. The implementation of the GIS module has enhanced pavement management capabilities by generating data that had previously been unavailable and by allowing faster access to the data (*59*).

KDOT has developed several spatial PMS applications. For example, a GIS was used to relate weather data available from point sources to their highway network to evaluate the effects of weather on pavement performance. The weather information from the National Oceanic and Atmospheric Administration was given for point stations. The information available for the point stations was assigned an effective radius of 20 mi and the resulting data were overlaid with the counties. This procedure permitted applying point data (such as the number of freeze–thaw cycles at a station) to a county and the highways within that county and studying the effect of weather; for example, rainfall, cold, heat, or freeze–thaw cycles, and pavement performance history. Other examples include (R. Miller, KDOT, personal communication, June 30, 2003):

- Using a GIS to identify "redundant" profile data to asses the variability of the data collection procedure,
- Assessing the feasibility of using FWD in network-level analyses by visualizing the coverage and distribution of FWD tests conducted over a period of 4 years,
- Identifying sample routes to evaluate provisional standards for pavement surface data collection, and
- Displaying remaining service-life estimations using PMS data at the network level to support the identification of reconstruction project locations.

Another interesting application of spatial technologies for supporting PMS is the georeferencing engine that KDOT is developing to support automated field data collection activities. This system integrates several years of GPS data points to determine roadway location in a three-dimensional space by developing a complete highway spatial model with a level of fidelity that approaches that of design plans. This engine, combined with county boundaries, permits associating GPS with county milepost (LRS) on a route and expanding PMS data collection capabilities to enhance the agency's geometric database (*60*).

EXAMPLES AT THE LOCAL LEVEL

At the local level, counties and cities have developed many GIS-based applications for PMS and infrastructure management systems. One important feature for local applications is that GIS can help coordinate work among assets (*61*). A very large number of examples are available in the literature; selected examples include the following:

- Lee et al. (*62*) integrated a PMS with a GIS for a selected town in Rhode Island. The system included the following functions: performance prediction, network programming, and M&R alternatives selection.
- Lee et al. (*63*) developed a GIS-based PMS software to enhance pavement management for Salt Lake City, Utah. As part of this effort, a GIS was developed to enhance the existing PMS. The program reads pavement conditions, recommends appropriate maintenance strategies, and displays those strategies on a digital map.
- Medina et al. (*64*) combined a road surface management system with a GIS to develop a PMS for the town of Fountain Hills, Arizona.
- The city of Woodinville in Washington State developed a low-cost GIS-based roadway facility information system (*65*).
- The Hillsborough County, Florida, Department of Public Works integrated its roadway centerline maps, inventory data, and pavement condition data using a GIS. Data collection was conducted using a van equipped with digital cameras.
- Ollerman and Varma (*66*) used GIS and CAD technologies in an airport PMS.

CHAPTER FIVE

IMPLEMENTATION STRATEGIES

This chapter covers the approaches used for integrating PMS and GIS, the different GIS tools used to support pavement management decisions, and other implementation-related issues. The level of satisfaction, advantages, problems, and solutions are discussed.

GEOGRAPHIC INFORMATION SYSTEM–PAVEMENT MANAGEMENT SYSTEM INTEGRATION APPROACHES

Some of the principal issues involved in designing a PMS that can be integrated into a GIS environment include the layout and on-line creation of pavement polygons, database design considerations, and the development of linkages between relational databases and map files (*67*). Cheetham and Beck (*68*) identified three possible approaches for PMS–GIS integration: total integration by developing the PMS in the GIS software, exporting information from the PMS and using it in the GIS for display, and importing map information from the GIS into the PMS. The developers chose the third approach for developing a PMS that incorporates map display capabilities for the South Carolina DOT; however, it was made clear that the most appropriate approach would be agency dependent. The transfer of the map features is updated annually.

SPATIAL TECHNOLOGIES USED

There are a series of spatial and mapping technologies and tools available to support the development and enhancement of PMS, including automatic mapping tools, GIS packages in the traditional sense, data management systems with enabled spatial capabilities, and middleware applications developed to support highway and asset management.

The main GIS packages currently in use by DOTs are the ESRI family of products (20 agencies or 74% of the agencies using a GIS) and the Intergraph products (9 agencies or 33% of the agencies using a GIS), with some DOTs using both product lines. Only three states indicated that they use other spatial packages: one agency indicated that they use Deighton's dTIMS software, another that they have developed their own software, and the third did not specify the software used. The level of satisfaction of PMS users in five key areas—user friendliness, learning curve, technical support, flexibility, and functionality—are summarized in Table 3. Overall, PMS users are neutral or satisfied with both product lines. Only a small number of respondents indicated dissatisfaction with some of the areas or features.

IMPLEMENTATION ISSUES

There are different approaches for developing spatial tools for PMS. The spatial applications that have been developed to support PMS that range from simple interfaces that input and output data into and out of a GIS to sophisticated models that take advantage of advanced spatial analysis capabilities. The implementation of the spatial or GIS-based tools could be approached as an individual effort of the PMS group or as an agency-wide cooperative effort. Each approach has its advantages and disadvantages. However, AASHTO (*4*) indicates that, in general, the use of a PMS alone does not justify the use of a GIS because of the significant effort required for its development. The main issues to be considering for the development and implementation of spatially supported PMS tools include selecting appropriate spatial tools, developing a base map, linking the attributes or PMS data to the spatial and cartographic information, and developing the PMS tools.

Zhang et al. (*69*) reviewed the different issues involved with the implementation of successful GIS-based PMS tools in the Texas DOT. The issues identified included the information technologies themselves, personnel and their GIS skills, the organizational structure within which they work, and the institutional relationships that govern the

TABLE 3
LEVEL OF SATISFACTION OF PMS USERS WITH MAJOR GIS PRODUCT LINES USED

Satisfaction Level	GIS Software Tools			
	Satisfied	Neutral	Dissatisfied	Total
User Friendliness	22 51%	19 44%	2 5%	43
Learning Curve	20 47%	20 47%	3 7%	43
Tech Support	16 37%	24 56%	3 7%	43
Flexibility	23 53%	19 44%	1 2%	43
Functionality	23 53%	18 42%	2 5%	43

Notes: Percentages are based on the number of DOTs providing this information (43).

TABLE 4
GIS IMPLEMENTATION APPROACHES FOLLOWED BY DOTs

Implementation Approach	No. of DOTs That Used the Approach		No. of DOTs That Used and Recommended the Approach	
Individual PMS Effort	9	28%	4	44%
Agency-Wide Effort	15	47%	12	80%
Other	2	6%	—	—
Don't Know	6	19%	—	—

Notes: Percentages are based on the number of DOTs providing this information (32).

management of information flow. The researchers proposed a three-stage implementation plan that included assessing the current practice, defining the visionary system, and identifying the intermediate solutions. However, a less ambitious approach was actually implemented by the Texas DOT.

Table 4 presents a summary of the GIS implementation approaches followed by the agencies that responded to the survey. The table also indicates the percentage of respondents that would recommend that approach. It is clear from the responses that there is no one-size-fits-all option. Approximately one-half of the agencies that are using a GIS to support a PMS (15) approached the GIS implementation as an agency-wide effort, and most of them would recommend that approach. On the other hand, nine agencies developed GIS-based tools as an individual PMS effort, and fewer than half of these agencies indicated that they would recommend this approach. This disparity seems to indicate that the agency-wide approach appears to be more effective, which is consistent with AASHTO recommendations (*4*).

Base Maps

Because most DOTs already have significant GIS activities and DOTs for many years have typically compiled annual highway maps, base maps are normally available. These base maps have been developed based on orthophotos, satellite imagery, digitized maps prepared using CAD/CAM tools, GPS-collected data, or, most commonly, a combination of these techniques. Although network-level applications normally use scales of 1:12,000 to 1:24,000, project-level studies and engineering applications require more precision, and scales of 1:120 to 1:1,200 are common (*18*).

Cost-Effectiveness

One of the main questions about the implementation of spatial tools for PMS is whether the benefits will outweigh the costs of developing the tools and implementing the GIS database. Costs associated with GIS development include hardware and software purchasing and maintenance and labor (including training) for designing, developing, and maintaining the databases and applications. The main cost is data; approximately 80% of the costs of developing a GIS are data related, and 80% of these data collection costs are for data items that will typically be shared across applications (e.g., road network file). Therefore, the development of the spatial tools is, in general, a large enterprise-wide effort. The DOTs that have developed spatial tools for PMS generally agree that it is cost-effective. Seventeen of the DOTs (55%) indicated that they agree or strongly agree with the following statement: "based on my experience, the use of spatial technologies for developing PMS applications is cost-effective." Five (19%) were neutral, six (23%) did not know, and only one of the respondents disagreed with the statement.

An example of quantifiable benefits is reported by Gharaibeh et al. (*70*). The benefits of developing a prototype GIS-based methodology for integrating highway infrastructure management activities were listed in four major areas: integrated computerized system, network-level integration, project-level integration, and multiple performance measures. The project-level integration included a spatial application for identifying adjacent improvement projects from various infrastructure components that can be implemented simultaneously to reduce traffic disruptions. The application of the integrated system approach to five infrastructure components (pavements, bridges, culverts, intersections, and signs) of the state highway system in an Illinois county showed that coordinating project implementation may reduce by 20% disruption to normal traffic flow caused by rehabilitation and reconstruction activities in a 5-year program.

The effectiveness of using GIS is more evident when it is approached as an agency-wide effort. For example, Table 5 presents estimated costs and benefits of implementing GIS-T in the Florida DOT during a 5-year period (*15*). Costs include application development, software, hardware, network, end-user training and retention of information technology support staff, additional GIS staff, and other contracts. Benefits include cost savings in data collection; storage, analysis, and output; income generated; and cost reductions because of productivity enhancement, data integration, and reduced redundancy. Although the costs exceed the benefits in the first few years, the long-term benefits are significantly higher than the costs.

TABLE 5
EXAMPLES OF COSTS AND BENEFITS OF IMPLEMENTING GIS-T (*15*)

Year	Costs	Benefits	Net Benefit*
(1) 1996–97	$625–1,900K	$0–200K	$(625)–(1,700K)
(2) 1997–98	$850–2,300K	$100–400K	$(750)–(1,900K)
(3) 1998–99	$1,050–2,250K	$650–2,000K	$(400)–(250K)
(4) 1999–00	$800–1,750K	$1,050–3,000K	$250–1,250K
(5) 2000–01	$750–1,700K	$1,700–4,500K	$950–2,800K

*Amounts in parentheses denote negative benefits.

Hall (*34*) presented an investigation of the costs and benefits of implementing an enterprise-wide GIS in the Illinois DOT. The study approached the implementation process with an executive focus on costs and benefits. Fourteen major GIS projects were identified based on management priority, ease of implementation, and user commitment. A comprehensive cost–benefit analysis was developed. A PMS was one of the projects identified. The greatest portion of costs over a 10-year period was for personnel (67%) and consultant services (19%). Although the total estimated cost of the 10-year effort was almost $12 million, starting on the seventh year, the estimated efficiency and effectiveness benefits clearly outweighed that cost. The net present value of the project using a 3% discount rate was $24 million, and the internal rate of return was 99.8%. The researchers estimated a benefit of $4.8 million annually, because of more effective pavement management decisions alone (*71*).

IDENTIFIED PROBLEMS

The main problems identified with the development or use of spatial (e.g., GIS-based) PMS applications include the following:

- Ensuring consistency among referencing systems, because most DOTs use different referencing methods (e.g., county/route/mile point, link/node, and centerline). Although many GIS and middleware providers have developed tools to assist in making the use of different location referencing methods transparent to the user, many of the software versions currently in use do not include these capabilities.
- The labor-intensive nature of the database updates needed to incorporate spatial information and corrections to the base maps. One agency, however, reported that this problem actually had some positive effects because developing a GIS-based application has helped find and correct questionable data in the PMS database, thereby increasing the quality of the database and correspondingly user confidence and system credibility.
- The accuracy of GPS-collected data may not be appropriate for PMS data collection in those areas where real-time differential correction is not available.
- Unresolved problems concerning the handling of temporal issues among data sets and the coordination of PMS data that are somehow static with more dynamic GIS data.
- Different users requiring different levels of detail to describe the network.
- Excessive user expectations; some users wanted access to everything with the click of a mouse.
- Some of the applications require a significant learning curve to be able to understand and use the GIS software and procedures.

Many of the problems identified relate more to database design and connectivity and PMS application development than to the spatial technologies used. States have invested significant resources to develop applications over the last 2 or 3 decades and, in many cases, have not been able to keep up with the very fast technological advancements of the last decade.

SUGGESTED GEOGRAPHIC INFORMATION SYSTEM ENHANCEMENTS

Many commercial GIS and spatial analysis middleware providers are continuously improving their products and adapting to the needs of the various users. However, many of the packages currently in use do not include all the functions that are required for pavement management. The following list summarizes the main GIS enhancements that were identified by the DOTs as needed to support better highway management:

- Better automatic techniques and procedures to facilitate the integration and resolution of data collected and stored using different location referencing methods. For example, it is very important that the historical condition and M&R records that are stored using route/milepost referencing be integrated with newer data collected by GPS-equipped automated data collection vehicles. The data conversion procedures could be used to develop real-time, in-field maps for GPS-based pavement condition data collection displays. These graphic interfaces would facilitate reconciling the data collected with existing centerline data and historical data.

- Enhanced map matching or conflation techniques to overlap existing maps with each other and with data collected using GPS to facilitate data sharing and integration among highway management systems.
- Incorporation of data with a temporal dimension to handle changes in the roadway geometry and alignment, pavement condition and structure capacity, and maintenance treatments and costs. The majority of survey respondents (82%) agrees or strongly agrees that this feature is important for developing PMS applications and providing easy access to historical data. One example would be the development of pavement performance prediction models by geographical or jurisdictional region.
- Enhanced dynamic segmentation capabilities; that is, the ability to track multiple and overlapping linear objects, events, or conditions.
- Enhanced database management capabilities to facilitate agency-wide enterprise integration and integration of PMS with other maintenance management and highway management systems. The system should be able to store not only attribute and spatial data but also temporal (timing of maintenance activities) and multimedia (photolog and videolog files) data and metadata.

Many of these enhancements were also identified by NCHRP Project 10-27(3) and have been incorporated into the newest versions of GIS packages and highway management middleware applications. The identified enhancements will not only strengthen PMS but will also help improve data quality and accessibility throughout the organization and, therefore, streamline the work processes.

When asked about GIS improvements, several agencies indicated that they would like to have truly GIS-based PMS tools. They would like to have a PMS that would be able to automatically generate professional looking maps that show, for example, relative current and/or future pavement conditions, locations of candidate projects, scheduled works, and the impact of funding allocations for system-wide asset decision support. Other desired functional requirements include the ability to store, manage, and display road images; provide direct links with related databases (without needing to import and export data); and supply access and query data through user-friendly interfaces.

CHAPTER SIX

CONCLUSIONS

Pavement and asset management systems are supported by collecting and retaining a tremendous amount of information, which is normally available in a wide variety of formats, referencing systems, and media. Geographic Information Systems (GIS) and other spatial data management and analysis technologies are particularly appropriate for integrating, managing, and analyzing these data. Therefore, many agencies have been actively pursuing the use of GIS and other spatial technologies for developing pavement management systems (PMS) applications. There is a significant body of knowledge on the application of spatial tools for transportation and, in particular, for enhancing pavement management processes, as shown by the literature reviewed.

The principal findings concerning the state of the practice and knowledge of pavement management applications using GIS and other spatial technologies include the following:

- Most departments of transportation (DOTs) are either currently using or are planning to use GIS or other spatial technologies to support pavement management activities. Sixty percent of the agencies surveyed reported that they are currently using spatial applications. Several of the remaining agencies indicated that although a GIS is not used to support PMS decisions, it is used to prepare maps and displays. Many applications have been reported in the literature.
- The major current application of GISs is for preparing maps. Approximately one-half of the DOTs also use spatial database management tools to help them with data integration among various departments. Only a very limited number of respondents indicated that they are using some of the spatial analysis capabilities. However, the planned activities show a trend toward the use of more advanced GIS capabilities, such as supporting data collection, data integration, and spatial analysis.
- In most DOTs, at least some of the data used by the PMS (inventory, pavement condition, traffic, and/or construction and maintenance history) is collected and maintained by a different department or division within the DOT, thus requiring integration for decision support. Automated data collection equipment is used to acquire at least part of their inventory and condition data.
- All of the agencies surveyed are using a linear referencing system for their PMS data collection and storage. However, because of the increased use of GIS, automated data collection equipment, and global positioning systems (GPS), coordinate-based referencing methods are also becoming popular. Approximately one-third of the agencies surveyed also use longitude and latitude.
- Data integration is very important as agencies move toward more global asset management approaches to comprehensively manage different types of transportation assets. However, the number of agencies that have actually completed or are close to completing a full integration of the systems is limited. Most survey respondents (79%) indicated that they agree or strongly agree that spatial applications may facilitate integrating PMS with wider asset management initiatives, a premise that is also supported by the literature reviewed.
- There are a series of spatial and mapping technologies and tools available to support the development and enhancement of PMS. These include automatic mapping tools, traditional GIS packages, data management systems with enabled spatial capabilities, and middleware applications developed to support highway and asset management. In general, users are satisfied or neutral with respect to the user friendliness, learning curve, technical support, flexibility, and functionality of these packages.
- Implementation of the spatial or GIS-based tools has been approached as an individual effort by the PMS group or as an agency-wide cooperative effort. Approximately one-half of the state DOTs approached the GIS implementation as an agency-wide effort, and most recommended that approach. On the other hand, nine agencies developed GIS-based tools as an individual PMS effort, and fewer than half of these agencies indicated that they would recommend this approach. This disparity seems to indicate that the agency-wide approach appears to be more effective, which is consistent with the literature reviewed.
- The main problems identified with the development and use of spatial (e.g., GIS-based) PMS applications are related to the use of different referencing methods, the level of effort required to develop and maintain the spatial-enabled databases, and the handling of temporal issues. Other problems reported included differences among users in the level of detail required to describe the network, accuracy of GPS-collected data when real-time differential correction is not available, excessive user expectations, and the steep

learning curve required of users to be able to understand and use the GIS software and procedures. Many of the problems identified relate more to database design and connectivity and PMS application development than to the spatial technologies used.

- The main improvements that were identified for using GIS and other spatial techniques to develop PMS tools include (1) better automatic techniques and procedures to facilitate the integration and resolution of data collected and stored using different linear referencing methods; (2) enhanced map-matching techniques; and (3) incorporation of temporal dimensions to handle changes in the roadway geometry and alignment, pavement condition and structure capacity, and maintenance treatments and costs. Enhanced dynamic segmentation capabilities and database management capabilities to facilitate system integration are also important. These enhancements will not only improve PMS but will also help advance data quality and accessibility throughout the organization and, hence, streamline the work processes.

Based on the survey conducted and the literature reviewed, it can be concluded that GIS and other spatial analysis tools provide effective alternatives for developing PMS tools. Current state of the practice includes the use of GIS and other spatial tools for map generation and database integration. GIS can be useful for preparing colored maps and graphic displays of information. Spatial database management systems, such as those included in GIS and other tools, are very useful for facilitating the integration of data with graphic information and with different data sets.

Spatial analysis tools and technologies may allow for more advanced analysis. Examples include performance prediction by jurisdiction, geographic integration of sections into projects, and resource allocation among districts or regions. Many GIS packages and highway management spatial tools have incorporated the spatial modeling capabilities and functionality necessary for conducting these types of analyses. Only a very limited number of states are currently using spatial analysis tools as part of the PMS decision-making process.

Although the use of GPS has many potential advantages in terms of location accuracy and data integration, it also creates a significant challenge regarding compatibility with historical data and interoperability with existing systems. These are the main problems reported with the use of spatial tools for pavement and asset management systems.

The following topics are suggested for future research based on the results of the synthesis and the problems identified:

- Identification and demonstration of “best management practices” of data integration with other asset management systems.
- Identification of optimal procedures to archive and yet include historical data into spatial analysis PMS procedures, such as pavement performance modeling by region and impact analysis.
- Development of automatic methods and procedures to incorporate GPS and other automatically collected data into linear referencing and coordinate systems automatically and seamlessly.
- Cost-effectiveness analysis of the development of spatial tools for pavement and asset management.
- Development of a framework for developing truly spatially enabled PMS methods, procedures, and tools.
- Investigation of the need and content for a workshop or training course and materials specifically on the use of GIS to support pavement management.

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ACRONYMS AND ABBREVIATIONS

AMS—Asset management system
CAD—Computer-assisted design
CAM—Computer-assisted mapping
DBMS—Database management system
DMI—Distance measuring instrument
DSS—Decision support system
ESAL—Equivalent single-axle load
FWD—Falling weight deflectometer
GIS—Geographic Information Systems
GIS-T—GIS for Transportation
GPS—Global positioning system
HTRIS—Highway Traffic Records Information System
ISTEA—Intermodal Surface Transportation Efficiency Act of 1991
ITS—Intelligent Transportation Systems
LRS—Linear referencing system
M&R—Maintenance and rehabilitation
NHI—National Highway Institute
PMS—Pavement management system
RTDC—Real-time differential correction

APPENDIX A

Survey Questionnaire

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP Project 20-5, Synthesis Topic 34-11

PAVEMENT MANAGEMENT APPLICATIONS USING GEOGRAPHIC INFORMATION SYSTEMS

INTRODUCTION:

The National Cooperative Highway Research Program (NCHRP) is preparing a synthesis to document the state of the practice and knowledge of pavement management applications using GIS and other spatial analysis technologies. The synthesis report will address sources of data and means for collecting data (including GPS), linear referencing methods used between pavement management and other systems, means for storing, managing, and disseminating pavement information, and GIS techniques and geospatial technologies used to support pavement management decisions. The report will also address important implementation issues.

You are being asked to provide information on spatial PMS applications in your state. These applications may include those that are currently in the planning or developmental stages as well as those that have already been implemented. We are also interested in determining what GIS features are needed to develop more powerful and effective applications for PMS. The information you supply will be used to develop a synthesis report on this important topic.

This survey is dynamic and the questions you are asked will depend on previous responses. Because the emphasis of this questionnaire is on both Pavement Management Systems (PMS) and Geographical Information Systems (GIS), please identify your area of expertise.

☐ PMS ☐ GIS ☐ PMS & GIS ☐ Neither PMS nor GIS

If the answer is *Neither*, display: "You have received this survey by mistake, please disregard the message and do not complete the survey."

Please provide the following information about yourself.

Please complete this survey by ________________ and return it to ________________________________

Name: ____

Current Position/Title: ____

Agency: ____

Address: ____

City: ______________________ State: ______________ Zip: __________

Telephone: ______________________ Fax: ______________________

E-mail: ____

Note: All of the information you provide in the survey will be stored in a database so that you can leave this survey and come back without having to fill out the form again. In order to ensure accuracy, privacy, and confidentiality, you will have to follow a "special link" if you wish to return to this survey with your responses preserved. Upon pressing the "submit" button of this survey, a message will be emailed to the email address you provide here. The message will contain instructions on how to get back to your responses before the survey stop date, 22 April 2003.

2. **Does your PMS use GIS or other geospatial applications?**
☐ Yes ☐ No, Skip to Question 3 ☐ Don't know

2a. Please indicate how you would best describe the level of integration between the PMS and GIS or other geospatial technologies? (*check all that apply*)

☐ GIS (or other geospatial technology) is only used to present PMS graphical displays and maps
☐ GIS or other geospatial technologies are used for managing the PMS database
☐ GIS or other geospatial technologies are used for managing the central DOT database and including the PMS
☐ GIS or other geospatial technologies are fully integrated with the PMS; i.e., the PMS functions take advantage of the enhanced spatial analysis.
☐ Other ____ (*please specify*)

2b. What are the main uses of the GIS and other geospatial applications for pavement management within your organization? (*check all that apply*)

☐ Map Generation

- What types of maps are currently generated? (*check all that apply*)
  - ☐ Inventory
  - ☐ Sample locations for data collection
  - ☐ Condition maps
  - ☐ Performance prediction maps
  - ☐ Needs analysis/candidate projects for optimization or prioritization
  - ☐ Work program maps (scheduled projects)
  - ☐ Impact analysis
  - ☐ Other ____ (*please specify*)

☐ Data Integration

- What other management systems share information with your PMS? (*check all that apply*)

	Integrated with PMS via GIS or other geospatial applications?	Uses same referencing system as PMS?
☐ Bridge (BMS)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know
☐ Highway Safety (SMS)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know
☐ Traffic Congestion (CMS)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know
☐ Public Transportation Facilities and Equipment (PTMS)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know
☐ Intermodal Transportation Facilities and Systems (ITMS)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know
☐ Maintenance Management (MMS)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know
☐ Asset Management (AMS)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know
☐ Other: ____________ (*please specify*)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know

☐ Spatial Analysis

- Please indicate which of the PMS's functions use spatial analysis. (*check all that apply*)
  - ☐ Inventory
  - ☐ Condition assessment
  - ☐ Performance prediction (e.g., performance analysis by maintenance area, soil type, or climatic/weather condition)
  - ☐ Needs analysis
  - ☐ Optimization or prioritization

☐ Work program preparation (e.g., grouping projects based on proximity or other spatial attributes)
☐ Impact analysis
☐ Public information
☐ Other ____________________ (*please specify*)

3. **Does your agency plan any spatial (GIS-based) applications to support pavement management activities?**
☐ Yes ☐ No, Skip to Question 4 ☐ Don't know

3a. What are the planned uses of GIS or other geospatial applications for pavement management within your organization? (*check all that apply*)

☐ Map Generation

- What types of maps do you plan to generate? (*check all that apply*)
  ☐ Inventory
  ☐ Sample locations for data collection
  ☐ Condition maps
  ☐ Performance prediction maps
  ☐ Needs analysis/candidate projects from optimization or prioritization
  ☐ Work program maps (scheduled projects)
  ☐ Impact analysis
  ☐ Public information
  ☐ Other ____________________ (*please specify*)

☐ Data Integration

- What systems do you plan to integrate with PMS via GIS or other geospatial applications? (*check all that apply*)

	Integrated with PMS via GIS or other geospatial applications?	Uses same referencing system as PMS?
☐ Bridge (BMS)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know
☐ Highway Safety (SMS)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know
☐ Traffic Congestion (CMS)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know
☐ Public Transportation Facilities and Equipment (PTMS)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know
☐ Intermodal Transportation Facilities and Systems (ITMS)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know
☐ Maintenance Management (MMS)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know
☐ Asset Management (AMS)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know
☐ Other: ____________(*please specify*)	☐ Yes ☐ No ☐ Don't Know	☐ Yes ☐ No ☐ Don't Know

☐ Spatial Analysis

- Which of the following PMS functions will use spatial tools? (*check all that apply*)
  ☐ Inventory
  ☐ Condition assessment
  ☐ Performance prediction (e.g., performance analysis by maintenance area, soil type, or climatic/weather condition)
  ☐ Needs analysis
  ☐ Optimization or prioritization
  ☐ Work program preparation (e.g., grouping projects based on proximity or other spatial attributes)
  ☐ Impact analysis
  ☐ Public Information
  ☐ Other ____________________ (*please specify*)

4. **Please indicate which of the following data are collected or used by our PMS.** (*check all that apply*)

	Data are Collected by?	Data Collection Method?	Data Collected with GIS/GPS?
☐ Road inventory	☐ PMS ☐ Other	☐ Manual ☐ Auto ☐ Both	☐ Yes ☐ No ☐ Don't Know
☐ Pavement condition	☐ PMS ☐ Other	☐ Manual ☐ Auto ☐ Both	☐ Yes ☐ No ☐ Don't Know
☐ Traffic volume	☐ PMS ☐ Other	☐ Manual ☐ Auto ☐ Both	☐ Yes ☐ No ☐ Don't Know
☐ Equivalent single-axle loads (ESALs)	☐ PMS ☐ Other	☐ Manual ☐ Auto ☐ Both	☐ Yes ☐ No ☐ Don't Know
☐ Maintenance and rehabilitation history	☐ PMS ☐ Other	☐ Manual ☐ Auto ☐ Both	☐ Yes ☐ No ☐ Don't Know
☐ Other: ____________ ____________________	☐ PMS ☐ Other	☐ Manual ☐ Auto ☐ Both	☐ Yes ☐ No ☐ Don't Know

4a. If GIS/GPS is used to collect certain data: Your answer to the previous question indicated that you use GIS/GPS to collect certain data. What (if any) processing is done to these data? (*check all that apply*)
☐ No correction, static GPS
☐ Real-time differential correction
☐ Post-processing differential correction
☐ Map matching (to overlap potentially incongruent GPS collected data and GIS maps)

5. **In what media are the PMS data stored?** (*select one*)
☐ Electronic files
☐ Paper files (notebook, binders, etc.)
☐ Both paper and electronic files
☐ Not sure
☐ Other ____ (*please specify*)

5a. If electronic files are used to store PMS data: How are your electronic files stored?
☐ Flat files or text files
☐ One independent database
☐ More than one independent database
☐ Related databases with different referencing methods
☐ Related databases with a consistent referencing method
☐ Central enterprise-wide database
☐ Not sure

6. **How are the data shared across the agency and with the public?**
☐ Available upon request
☐ Printed report
☐ Internet accessible
☐ Other ____ (*please specify*)

7. **Geospatial applications facilitate integrating PMS with wider asset management initiatives.**
☐ Strongly agree
☐ Agree
☐ Neither agree nor disagree
☐ Disagree
☐ Strongly disagree
☐ Don't know

8. **We are interested in how your PMS stores data over time. How does your PMS compile historical data (e.g., pavement condition data)?**
☐ Data are replaced by newly collected data, and the data are periodically archived
☐ PMS stores sequential temporal records
☐ Not sure

9. **The ability of a geospatial tool to handle time-dependent records and functions (e.g., historical pavement condition) is important for the development of PMS applications.**
   ☐ Strongly agree
   ☐ Agree
   ☐ Neither agree nor disagree
   ☐ Disagree
   ☐ Strongly disagree
   ☐ Don't know

10. **What types of referencing systems are currently used in your PMS?** (*check all that apply*)
    ☐ Linear
    Please select the linear referencing systems (LRS) currently used in your PMS? (*check all that apply*)
    ☐ Route and milepost
    ☐ Landmark referencing
    ☐ Node coordinates (e.g., latitude/longitude or state plane)
    ☐ Other ____ (*please specify*)

    ☐ Area
    Please select the area referencing systems currently used in your PMS? (*check all that apply*)
    ☐ Region/district
    ☐ County
    ☐ City
    ☐ Other ____ (*please specify*)

11. **Please identify up to three GIS enhancements that you think would improve your PMS applications.**
    1. ____
    2. ____
    3. ____

If answered "Yes" to Question 2:

12. **Please indicate the geospatial package used for developing the PMS applications**. (*check all that apply*)
    ☐ Intergraph family of products: Geomedia, MGE
    ☐ ESRI family of products: ArcGIS, ArcView, ArcInfo
    ☐ MapInfo products
    ☐ Bentley Geographic products
    ☐ Other ____ (*please specify*)

    - Please indicate your level of satisfaction with the following fixtures of the geospatial technology used:

User friendliness	☐ Satisfied	☐ Neutral	☐ Dissatisfied
Learning curve	☐ Satisfied	☐ Neutral	☐ Dissatisfied
Technical support	☐ Satisfied	☐ Neutral	☐ Dissatisfied
Flexibility	☐ Satisfied	☐ Neutral	☐ Dissatisfied
Functionality	☐ Satisfied	☐ Neutral	☐ Dissatisfied
Other _______ (*please specify*)	☐ Satisfied	☐ Neutral	☐ Dissatisfied

13. **Are your spatial PMS applications web-enabled? Please differentiate between full Internet and intranet access.**
    ☐ Yes, Internet-enabled
    ☐ Yes, but only intranet-enabled
    ☐ No, there is no web access

14. **Please list up to three problems found when developing or using spatial (e.g., GIS-based) PMS applications.**
    1. ____
    2. ____
    3. ____

15. **Based on my experience, the use of geospatial technologies for developing PMS applications is cost-effective.**
- ☐ Strongly agree
- ☐ Agree
- ☐ Neither agree nor disagree
- ☐ Disagree
- ☐ Strongly disagree
- ☐ Don't know

16. **How would you best describe the implementation approach for the geospatial PMS applications described? Please also indicate if you would recommend that approach to other agencies.**

☐ An individual effort of the PMS group	☐ Recommended	☐ Not recommended
☐ Part of an agency-wide effort	☐ Recommended	☐ Not recommended
☐ Other ________________________________ (*please specify*)	☐ Recommended	☐ Not recommended
☐ Don't know		

Click to save your reponses

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APPENDIX B

Summary of Survey Responses

TABLE B1
CURRENT AND PLANNED GIS APPLICATIONS

Area of Expertise	State	Uses GIS?	Level of Integration	Current Uses	Plan to Use?	Planned Uses
PMS & GIS	AK	Yes	PMS DB.	MG	Yes	MG
GIS	AK	Yes	Maps	MG	Yes	MG/DI
PMS	AL	Yes	Maps	MG	Yes	MG/DI/SA
GIS	AL	Yes	Maps	MG	Yes	MG/DI/SA
PMS	AR	No			Yes	MG
PMS	AZ	Yes	Maps	MG/DI	No	
PMS	BC	No			No	
PMS & GIS	CA	Yes	Maps	MG/DI/SA	Yes	MG/DI/SA
PMS	CO	No			No	
GIS	CO	Yes	Maps/Cent.DB.	MG/DI	No	
PMS & GIS	CT	Yes	Maps/PMS DB/Cent.DB.	MG/DI	Yes	MG/DI/SA
PMS	DE	No			No	
PMS	FL	No			Yes	MG/DI
PMS	GA	Yes	Maps		Yes	MG/DI/SA
GIS	HI	Yes	Maps	MG	Yes	MG/SA
PMS	IA	Yes	Cent.DB.	MG/DI	Yes	SA
PMS & GIS	IA	Yes	Maps/PMS DB./Cent.DB.	MG/DI	Yes	MG/DI/SA
PMS	ID	No			Yes	MG/DI/SA
GIS	ID	No			Yes	MG/DI/SA
PMS	IL	No	Other: (1)		DN	
GIS	IL	Yes	Integrated	MG/DI/SA	Yes	MG/DI/SA
PMS	IN	No			DN	
PMS & GIS	KS	Yes	PMS DB.	MG/DI/SA	Yes	MG/SA
GIS	KS	Yes	Integrated	MG/DI/SA	Yes	MG/DI/SA
PMS	KY	No			Yes	MG/DI
PMS	LA	Yes	Maps	MG/DI	Yes	DI
PMS	MD	Yes	Maps	MG	Yes	MG/DI/SA
GIS	MD	Yes	Cent.DB.	SA	DN	
PMS	ME	Yes	Maps	MG	Yes	MG/DI
GIS	ME	Yes	Maps/Cent.DB./Int.	MG/DI/SA	DN	DI
PMS	MN	Yes	Maps	MG	No	
GIS	MO	Yes	Cent.DB.	MG/DI	No	MG/DI/SA
PMS	MS	Yes	PMS DB./Cent.DB.	DI	DN	
GIS	MT	Yes	Maps	MG	Yes	MG/DI/SA
PMS	MT	No			Yes	MG/DI
PMS	N.B.	No			DN	
PMS	NC	Yes			Yes	MG/DI
PMS	ND	Yes	Maps	MG	No	
PMS	NE	Yes	Maps	MG/DI/SA	Yes	MG/SA
PMS	NH	Yes	Maps	MG	DN	
PMS	NJ	Yes	Maps	MG/DI	Yes	MG/DI/SA
GIS	NJ	Yes	Maps/Cent.DB.	MG/SA	Yes	MG/DI/SA
PMS	NL	No			Yes	MG/DI
PMS	NM	No			No	DI
PMS	NV	Yes	Maps/Other: (2)	MG/DI	Yes	

PMS & GIS	NY	Yes	Maps	MG/SA	Yes	MG/DI/SA
PMS	OH	Yes	Maps/PMS DB.	MG/DI	DN	
GIS	OH	Yes	Integrated	MG/DI/SA	Yes	MG/DI/SA
PMS	OK	No			No	
PMS & GIS	OK	Yes	Maps	MG/DI	Yes	SA
PMS	OR	No			No	
PMS	PA	No			No	
GIS	PA	Yes	Maps	MG/DI/SA	DN	MG/DI/SA
GIS	PEI	No			Yes	MG/DI
PMS	RI	Yes	Maps	MG	DN	
PMS	SC	Yes	Maps/Other (3)	MG/DI	Yes	MG/DI/SA
PMS	SD	Yes	Maps	MG	No	MG
PMS	SD	Yes	Maps	MG/DI/SA	Yes	MG/DI/SA
PMS	TN	DN			Yes	MG/DI/SA
GIS	TN	Yes	Cent.DB.	DI/SA	DN	
PMS	TX	Yes	Maps	MG	Yes	MG/DI/SA
PMS & GIS	TX	Yes	Maps	MG	DN	MG
PMS	UT	No			DN	
PMS & GIS	UT	Yes	Maps	MG/SA	Yes	MG/DI/SA
PMS & GIS	VA	Yes	Cent.DB.	MG/DI	Yes	MG/DI/SA
GIS	VA	Yes	Cent.DB.	MG/DI/SA	Yes	MG/DI/SA
PMS	VT	Yes	Maps	MG	Yes	MG/DI
PMS & GIS	VT	Yes	Maps/PMS DB.	MG/DI	Yes	MG/DI
PMS & GIS	WA	Yes	Maps	MG	Yes	MG/DI/SA
GIS	WA	Yes	Maps	MG	Yes	MG/DI/SA
PMS & GIS	WI	Yes	PMS DB./Cent.DB./Int.	MG/DI/SA	No	
PMS	WV	No	Maps	MG	Yes	MG/DI
PMS	WY	No			Yes	MG/DI

Maps = GIS (or other geospatial technology) is only used to present PMS graphical displays and maps; PMS DB. = GIS or other geospatial technologies are used for managing the PMS database; Cent.DB. = GIS or other geospatial technologies are used for managing the central DOT database and including the PMS; Int. = GIS or other geospatial technologies are fully integrated with the PMS; i.e., the PMS functions take advantage of the enhanced spatial analysis.

MG = map generation; DI= data integration; SA = spatial analysis; DN = don't know.

(1) Illinois uses GIS as a counterpart to PMS for data storage.
(2) We are currently waiting for the Linear Referencing System (LRS) to be completed so we can link our information to the new base map. This will also allow us to link to any and all other databases that use the LRS. Many of the management systems within the department use different reference systems and this will tie all of them together.
(3) Road Inventory Management System (RIMS) ; this is an enterprise-wide database for specified South Carolina DOT managers.

TABLE B2
PMS DATA COLLECTION METHODS

Area of Expertise	State	Data collected for PMS	Collected by PMS?					Collection Method				
			RI	PC	TV	ESAL	M&R	RI	PC	TV	ESAL	M&R
PMS & GIS	AK	RI/PC/TV/ESAL/MR	PMS	PMS	Other	Other	PMS	Auto	Auto	Both	Both	Manual
GIS	AK	RI/PC/TV/ESAL/MR		PMS	Other	PMS	PMS	Manual	Both	Both	Manual	Manual
PMS	AL	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	Other	Manual	Auto	Both	Manual	Manual
GIS	AL	RI/PC/TV/ESAL/MR	PMS	PMS	Other	Other	Other	Auto	Both	Both	Manual	Manual
PMS	AR	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	Other	Manual	Both	Auto	Manual	Manual
PMS	AZ	RI/PC/TV/ESAL/MR	Other	PMS	Other	PMS	PMS	Manual	Both	Both	Manual	Manual
PMS	BC	PC/MR		PMS			PMS		Auto			Manual
PMS & GIS	CA	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	PMS		Both			Both
PMS	CO	RI/PC/TV/ESAL/MR	PMS	PMS	Other	Other	Other	Manual	Manual	Auto	Auto	Manual
GIS	CO	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	PMS	Manual	Auto	Both	Manual	Both
PMS & GIS	CT	RI/PC/TV/ESAL/MR	Other	Other	Other	Other	PMS	Manual	Auto	Auto	Auto	Manual
PMS	DE	RI/PC/TV/MR	Other	PMS	Other		PMS	Manual	Manual	Manual		Manual
PMS	FL	RI/PC/TV/ESAL/MR										
PMS	GA	RI/PC/TV	Other	PMS	Other				Manual			
GIS	HI	RI/PC/TV/ESAL	Other	Other	Other	Other		Both	Auto	Both	Both	
PMS	IA	PC/TV/ESAL/MR		PMS	Other	Other	Other		Auto	Both	Auto	Manual
PMS & GIS	IA	RI/PC/TV/ESAL	Other	PMS	Other	Other		Both	Both	Both	Auto	
PMS	ID	RI/PC/TV/ESAL/MR	PMS	PMS	Other	Other	PMS	Both	Both	Auto	Auto	Manual
GIS	ID	RI/PC/ESAL	PMS	PMS		Other		Both	Both		Auto	
PMS	IL	RI/PC/TV/MR	Other	Other	Other		Other	Both	Both	Auto		Manual
GIS	IL	RI/PC/TV/ESAL/MR	PMS	PMS	Other	Other	Other	Both	Both	Both	Manual	Manual
PMS	IN	PC/MR		PMS			PMS		Both			Manual
PMS & GIS	KS	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	PMS	Manual	Both	Auto	Auto	Auto
GIS	KS											
PMS	KY	RI/PC/TV/ESAL/MR	PMS	PMS	Other	Other	PMS	Both	Both	Both	Both	Both
PMS	LA	RI/PC	Other	Other				Both	Both			
PMS	MD	RI/PC/TV/ESAL/MR	Other	PMS	Other	PMS	PMS	Both	Auto	Auto	Manual	Both
GIS	MD	PC										
PMS	ME	RI/PC/TV/MR	Other	PMS	Other		Other	Manual	Auto	Both		Both
GIS	ME	PC		PMS					Auto			
PMS	MN	RI/PC/TV/ESAL/MR	PMS	PMS	Other	Other	Other	Auto	Auto	Both	Both	Manual
GIS	MO	RI/PC/TV/ESAL	Other	PMS	Other	Other		Manual	Both	Auto	Auto	
PMS	MS	PC		Other					Both			
GIS	MT	RI/TV/ESAL										
PMS	MT	RI/PC/MR	PMS	PMS			PMS	Both	Manual			Manual
PMS	N.B.	PC/TV/ESAL/MR		PMS	PMS	Other			Both	Auto	Manual	Manual
PMS	NC	RI/PC/MR	Other	PMS	Other		PMS		Manual			Manual
PMS	ND	RI/PC	PMS	PMS				Auto	Auto			
PMS	NE	RI/PC/TV/MR	Other	PMS	Other		Other	Both	Both	Both		Manual
PMS	NH	RI/PC/TV/ESAL/MR	Other	Other	Other	Other	PMS	Both	Both	Both	Both	Manual
PMS	NJ	RI/PC/TV/ESAL/MR	PMS	PMS	Other	Other	PMS	Both	Both	Auto	Auto	Manual
GIS	NJ	RI/PC/TV										
PMS	NL	PC		PMS					Both			
PMS	NM	RI/PC/TV/ESAL/MR	Other	Other	Other	Other	Other	Both	Both	Manual	Manual	Manual
PMS	NV	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	PMS	Both	Both	Both	Both	Both
PMS & GIS	NY	RI/PC/TV/MR	PMS	PMS	Other		Other	Manual	Both	Both		Manual
PMS	OH	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	PMS	Manual	Manual	Both	Auto	Manual
GIS	OH	RI/PC/TV/ESAL/MR	Other	PMS	PMS	Other	Other	Manual	Both	Both	Both	Both
PMS	OK	RI/PC/TV/MR	Other	PMS	Other		Other	Manual	Auto	Auto		Manual
PMS & GIS	OK	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	PMS	Both	Auto	Auto	Both	Manual
PMS	OR	RI/PC/TV/MR	Other	PMS	Other		PMS		Manual			Manual
PMS	PA	RI/PC/TV/ESAL/MR	PMS	PMS	PMS	PMS	PMS	Auto	Both	Both	Both	Manual
GIS	PA	RI/PC/TV/MR	PMS	PMS	PMS		Other	Both	Auto	Both		Manual
GIS	PEI	RI/PC/TV/ESAL	PMS	PMS	Other	Other		Both	Manual	Auto	Auto	
PMS	RI	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	Other	Both	Auto	Both	Auto	Manual
PMS	SC	PC/MR		PMS			Other		Both			Manual
PMS	SD	RI/PC/TV/MR	Other	PMS	Other		PMS	Both	Both	Auto		Both
PMS	SD	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	Other	Manual	Both	Both	Both	Manual
PMS	TN	RI/PC/TV/MR	Other	PMS	Other		Other	Both	Both	Both		Manual
GIS	TN	RI/PC	Other	PMS				Both	Manual			
PMS	TX	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	Other	Both	Both	Both	Both	Manual
PMS & GIS	TX	PC		PMS					Both			
PMS	UT	RI/PC/TV/ESAL/MR	Other	Other	Other	Other	PMS	Both	Both	Both	Both	Manual

PMS & GIS	UT	RI/PC/ESAL/MR				Other	Other					
PMS & GIS	VA	RI/PC/TV/ESAL/MR	PMS	PMS	Other	Other	PMS	Both	Both	Both	Both	Manual
GIS	VA	RI/PC/TV	Other	PMS	Other			Auto				
PMS	VT	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	PMS	Auto	Auto	Both	Both	Both
PMS & GIS	VT	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	PMS	Both	Auto	Both	Both	Both
PMS & GIS	WA	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	Other	Both	Auto	Auto	Auto	Both
GIS	WA	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	Other	Both	Auto	Auto	Auto	Both
PMS & GIS	WI	RI/PC/MR	PMS	PMS			PMS	Manual	Manual			Manual
PMS	WV	PC/MR		PMS			PMS		Both			Manual
PMS	WY	RI/PC/TV/ESAL/MR	Other	PMS	Other	Other	PMS	Manual	Both	Both	Both	Manual

RI = road inventory; PC = pavement condition; TV = traffic volume; ESAL = equivalent single-axle loads; M&R = maintenance and rehabilitation history.

TABLE B3
CURRENT AND PLANNED MAP GENERATION AND SPATIAL ANALYSIS APPLICATIONS

Area of Expertise	State	Map Generation		Spatial Applications	
		Current	Planned	Current	Planned
PMS & GIS	AK	IN/CM/PP/WP/NA/OP	PI		
GIS	AK	IN/CM	IN/CM/PP/WP/NA/OP/PI		
PMS	AL	CM/PP/WP/NA/OP	IN/SL/CM/PP/WP/NA/OP		
GIS	AL	CM/PP	IN/CM/PP/WP/NA/OP/PI		IN/CA/PP/NA/OP/WP
PMS	AR		IN/SL/CM/PP/WP/NA/OP/IA		
PMS	AZ	Other: real-time MP location			
PMS	BC				
PMS & GIS	CA	IN/SL/CM/PP/WP/NA/OP	IN/SL/CM/PP/WP	IN/CA/NA/OP	IN/CA/PP/NA/OP/WP
PMS	CO				
GIS	CO	CM/PP/WP/NA/OP/PI			
PMS & GIS	CT	IN/SL/CM/WP	IN/SL/CM/PP/WP/NA/OP		IN/CA/PP/WP
PMS	DE				
PMS	FL		IN/SL/WP		
PMS	GA	IN/CM	IN/SL/CM/PP/WP/NA/OP		IN/CA/PP
GIS	HI	IN/CM	IN/CM		CA
PMS	IA	IN/CM/PP/WP/NA/OP/IA			IN/CA/PP/NA/OP/WP
PMS & GIS	IA	IN/CM/WP	IN/CM/PP/WP/NA/OP/IA/PI		IN/OP/WP
PMS	ID		IN/CM/WP/NA/OP/PI		IN/CA/NA/WP
GIS	ID		IN/SL/CM/PP/PI		IN/CA/NA/PI
PMS	IL				
GIS	IL	IN/CM/WP/PI	IN/CM/PP/WP/NA/OP/IA/PI	IN/CA/PP/WP/PI	IN/CA/PP/NA/OP/WP/IA/PI
PMS	IN				
PMS & GIS	KS	CM/WP/NA/OP	SL/PP	CA/OP/WP/PI	PP
GIS	KS	IN/SL/CM/PP/WP/NA/OP/IA			
PMS	KY		IN/SL/CM/PP/WP/NA/OP		
PMS	LA	CM/WP/NA/OP			
PMS	MD	IN/SL/CM/PP/WP/NA/OP	IN/SL/CM/PP/NA/OP		PP/NA/OP
GIS	MD				
PMS	ME	SL/CM/WP/NA/OP	SL/CM/WP/NA/OP		
GIS	ME	IN/SL/CM/WP/NA/OP/PI		IN/CA/OP/WP/PI	
PMS	MN	IN/CM/PP/WP/NA/OP			
GIS	MO	IN/SL/CM/PP/WP/NA/OP/IA /PI	IN/CM/NA/OP/PI		IN/CA/PP/OP/PI
PMS	MS				
GIS	MT	IN	IN/SL/CM		IN/CA
PMS	MT		IN/CM/PP/WP		
PMS	N.B.				
PMS	NC		SL/CM		CA/NA
PMS	ND	IN/SL/CM/WP/NA/OP/PI			
PMS	NE	CM/NA/OP	IN/CM/WP/NA/OP	IN/CA/NA	IN/CA/NA/OP/WP
PMS	NH	CM/WP/PI			
PMS	NJ	IN/SL/CM/WP/NA/OP	IN/CM/PP/WP/NA/OP/IA/PI		IN/CA/PP/NA/OP/WP/IA/PI
GIS	NJ	CM/WP/NA/OP	IN/CM/PP/WP/NA/OP/IA/PI	CA/NA/WP	PP/NA/OP/WP/IA/PI
PMS	NL		IN/SL/CM/NA/OP		
PMS	NM				
PMS	NV	IN/CM/WP/NA/OP/PI			
PMS & GIS	NY	IN/SL/CM	IN/CM/WP/NA/OP	IN/CA	IN/CA/NA/OP/WP
PMS	OH	IN/CM/WP			
GIS	OH	IN/SL/CM/PP/WP/NA/OP/PI		IN/CA/PP/NA/OP/WP	IN/CA/PP/NA/OP/WP
PMS	OK				
PMS & GIS	OK	IN/SL/CM/WP/NA/OP/IA/PI/ Other: straight line diagrams produced by PMS			CA/PP/NA/OP/WP
PMS	OR				
PMS	PA				
GIS	PA	IN/SL/CM/WP/NA/OP/PI		PI	
GIS	PEI		IN/CM/WP/NA/OP		
PMS	RI	CM/NA/OP			
PMS	SC	CM/WP/NA/OP/Other	IN/SL/CM/PP/WP/NA/OP		
PMS	SD	IN/CM/WP/PI			

PMS	SD	IN/SL/CM/WP/NA/OP/PI	IN/CM/PP/NA/OP/IA	IN/CA/NA/WP	IN/CA/NA/OP/WP/PI
PMS	TN		CM/PP/NA/OP/PI		CA/PP/NA/OP/PI
GIS	TN				
PMS	TX	IN/SL/CM/WP/NA/OP/PI	IN/SL/CM/PP/WP/NA/OP/IA /PI		IN/CA/PP/NA/OP/WP/IA/PI
PMS & GIS	TX	IN/SL/CM/PP/WP/NA/OP			
PMS	UT				
PMS & GIS	UT	CM/NA/OP/PI	IN/SL/CM	IN/CA/PP/OP	
PMS & GIS	VA	CM	IN/SL/WP/NA/OP/IA	CA	IN/CA/NA/WP/IA
GIS	VA	IN/SL/CM	IN/SL/CM		
PMS	VT	IN/SL/CM/WP/NA/OP/PI	IN/SL/CM/WP/NA/OP/PI		
PMS & GIS	VT	IN/SL/CM/PP/WP/NA/OP/IA /PI	IN/SL/CM/PP/WP/NA/OP/IA /PI		
PMS & GIS	WA	CM/WP/NA/OP	CM/PP/WP/NA/OP/PI		IN/CA/PP/PI
GIS	WA	CM/WP/NA/OP	CM/PP/WP/NA/OP/PI		IN/CA/PP/PI
PMS & GIS	WI	IN/SL/CM/PP		IN	
PMS	WV		IN/SL/CM		
PMS	WY		CM/WP/NA/OP		

Maps:
IN = inventory; CM = condition maps; SL= sample locations for data collection; PP = performance prediction maps; WP = work program maps (scheduled projects); NA = needs analysis; OP = candidate projects from optimization or prioritization; IA = impact analysis; PI = public information.

Spatial:
IN = inventory; CA = condition assessment; PP = performance prediction (e.g., performance analysis by maintenance area, soil type, or climatic/weather condition); NA = needs analysis; OP = optimization or prioritization; WP = work program preparation (e.g., grouping projects based on proximity or other spatial attributes); IA = impact analysis; PI = public information.

TABLE B4
PLANNED DATA INTEGRATION APPLICATIONS

Area of Expertise	State	Current Data Integration	Other	Planned Data Integration
PMS & GIS	AK			
GIS	AK			MMS
PMS	AL			BMS/MMS/AMS
GIS	AL			BMS/SMS/CMS/PTMS/ITMS/MMS/AMS
PMS	AR			
PMS	AZ			
PMS	BC			
PMS & GIS	CA	BMS/SMS/CMS/PTMS/ITMS/MMS/AMS		BMS/SMS/CMS/PTMS/ITMS/MMS/AMS
PMS	CO			
GIS	CO	BMS/CMS/ITMS		
PMS & GIS	CT	BMS/MMS		BMS/MMS
PMS	DE			
PMS	FL			MMS
PMS	GA			BMS/SMS/MMS/AMS
GIS	HI			
PMS	IA			
PMS & GIS	IA			BMS/SMS/MMS/AMS
PMS	ID			CMS/PTMS/ITMS/MMS/AMS
GIS	ID			BMS/SMS/CMS/PTMS/MMS/AMS
PMS	IL			
GIS	IL	BMS/SMS/CMS/PTMS/ITMS/MMS/AMS		MMS
PMS	IN			
PMS & GIS	KS	MMS/AMS/Other	Highway Inventory	
GIS	KS			
PMS	KY			BMS/MMS/AMS
PMS	LA	BMS/AMS		BMS/SMS/MMS/AMS
PMS	MD			AMS
GIS	MD			
PMS	ME			BMS/AMS
GIS	ME	BMS/SMS/CMS/AMS		
PMS	MN			
GIS	MO	BMS/SMS/CMS/ITMS/AMS		BMS/SMS/CMS/AMS
PMS	MS	BMS/SMS/AMS		
GIS	MT			BMS/SMS/CMS/PTMS/ITMS/MMS/AMS/ Other
PMS	MT			MMS
PMS	N.B.			
PMS	NC			MMS
PMS	ND			
PMS	NE	BMS/SMS		
PMS	NH			
PMS	NJ	SMS/CMS/MMS/AMS/Other	Traffic Volume	BMS/SMS/CMS/MMS/AMS
GIS	NJ			BMS/SMS/CMS/PTMS/ITMS/MMS/AMS
PMS	NL			BMS/AMS
PMS	NM			BMS/SMS/CMS/PTMS/ITMS/MMS/AMS
PMS	NV	SMS/MMS/AMS		
PMS & GIS	NY			BMS/SMS/MMS
PMS	OH	Other	Project Management System	
GIS	OH	BMS/SMS/CMS/MMS/AMS		BMS/SMS/CMS/MMS
PMS	OK			
PMS & GIS	OK	BMS/SMS/MMS/AMS/Other	(1)	
PMS	OR			
PMS	PA			
GIS	PA	BMS/SMS/MMS/Other	Project Management	

GIS	PEI			SMS/AMS
PMS	RI			
PMS	SC	AMS/Other	Project Selection	BMS/AMS/Other: RITMS (road inventory management)
PMS	SD			
PMS	SD	BMS/Other	Project Master System	AMS/Other: Concept to Contract Developed System
PMS	TN			BMS/MMS/AMS
GIS	TN	Other	(2)	
PMS	TX			MMS/Other: Traffic Inventory, Materials, Construction Work History
PMS & GIS	TX			
PMS	UT			
PMS & GIS	UT			BMS/SMS/CMS/MMS/AMS
PMS & GIS	VA	BMS/MMS/AMS		BMS/MMS/AMS
GIS	VA	BMS/CMS/MMS/AMS		BMS/CMS/MMS/AMS
PMS	VT			BMS/SMS/CMS/MMS/AMS
PMS & GIS	VT	BMS/SMS/CMS/MMS/AMS		BMS/SMS/CMS/MMS/AMS
PMS & GIS	WA			MMS
GIS	WA			MMS
PMS & GIS	WI	AMS		
PMS	WV			BMS
PMS	WY			BMS/SMS/AMS

Management Systems:
BMS = bridge; SMS = highway safety; CMS = traffic congestion; PTMS = public transportation facilities and equipment; ITMS = intermodal transportation facilities and systems; MMS = maintenance management; AMS = asset management.

(1) Rail crossings, HPMS, accident studies, needs study.

(2) TRIMS—Tennessee Roadway Information Management System (roadway inventory database).

TABLE B5
GPS USE FOR DATA COLLECTION

Area of Expertise	State	Data Collected with GPS?					GPS Data Processing
		Road Inventory	Pavement Condition	Traffic Volume	ESAL	M&R History	
PMS & GIS	AK	Yes	Yes	Don't Know	Don't Know	No	RTDC/PPDC/MM
GIS	AK	Yes	Yes	No	No	No	RTDC/MM
PMS	AL	Yes	Yes	No	No	No	NC/RTDC/PPDC/MM
GIS	AL	Yes	Yes	No	No	No	MM
PMS	AR	No	Yes	No	No	No	RTDC
PMS	AZ	Don't Know	No	Don't Know	No	No	
PMS	BC		No			No	
PMS & GIS	CA						
PMS	CO	No	No	No	No	No	
GIS	CO	Yes	No	No	No	No	RTDC/PPDC
PMS & GIS	CT	Yes	Yes	No	No	No	RTDC/PPDC/MM
PMS	DE	No	No	No		No	
PMS	FL						
PMS	GA	Don't Know	Don't Know	Don't Know			
GIS	HI	Yes	Yes	Yes	No		RTDC/PPDC
PMS	IA		Yes	Don't Know	Don't Know	No	
PMS & GIS	IA	No	Yes	No	No		PPDC
PMS	ID						
GIS	ID	Yes	No		No		PPDC
PMS	IL	Don't Know	Don't Know				
GIS	IL	Yes	Yes	Yes	No	No	RTDC
PMS	IN		No			No	
PMS & GIS	KS	No	Yes	Don't Know	Don't Know	No	RTDC/MM
GIS	KS						
PMS	KY	No	No	Don't Know	Don't Know	No	
PMS	LA	Yes	Yes				PPDC
PMS	MD	Yes	Yes	Yes	Don't Know	Yes	RTDC
GIS	MD						
PMS	ME	No	No	No		No	
GIS	ME		No				
PMS	MN	Yes	Yes	Don't Know	Don't Know	No	RTDC
GIS	MO	Yes	No				PPDC
PMS	MS		Yes				RTDC
GIS	MT						
PMS	MT	Yes					RTDC
PMS	N.B.		No	No	No	No	
PMS	NC		No			No	
PMS	ND	No	No				
PMS	NE	No	No	No		No	
PMS	NH	Yes	No	Don't Know	Don't Know	No	PPDC
PMS	NJ	Yes	Yes	Don't Know	Don't Know	No	RTDC
GIS	NJ						
PMS	NL		No				
PMS	NM	No	No	No	No	No	
PMS	NV	Don't Know	No	Don't Know	Don't Know	Don't Know	
PMS & GIS	NY	No	Yes	No		No	PPDC
PMS	OH	Don't Know	No	No	No	Don't Know	
GIS	OH	No	No	No	No	Yes	NC
PMS	OK	No	Yes	No		No	RTDC
PMS & GIS	OK	Yes	Yes	Yes	Yes	No	RTDC
PMS	OR	Don't Know	No	Don't Know		No	
PMS	PA	Yes	Yes	No	No	No	RTDC/PPDC
GIS	PA	Yes	No	No		No	MM
GIS	PEI	Yes	No	No	No		NC/MM
PMS	RI	Yes	Yes	No	Yes	Don't Know	RTDC/MM

PMS	SC		Yes			No	RTDC
PMS	SD	No	No	No		No	
PMS	SD	No	No	No	No	No	
PMS	TN	Don't Know	No	Don't Know		Don't Know	
GIS	TN	Yes	No				RTDC
PMS	TX	No	Yes	No	No	No	RTDC/MM
PMS & GIS	TX		No				
PMS	UT	Don't Know	Don't Know	No	No	No	
PMS & GIS	UT	Yes	Yes		Don't Know	Don't Know	PPDC/MM
PMS & GIS	VA	Yes	Yes	Don't Know	Don't Know	No	PPDC
GIS	VA	Yes					PPDC
PMS	VT	Yes	No	No	No	No	
PMS & GIS	VT	Yes	No	No	No	No	RTDC/MM
PMS & GIS	WA	No	No	No	No	No	
GIS	WA	No	No	No	No	No	
PMS & GIS	WI	No	No			No	
PMS	WV		Yes			No	NC
PMS	WY	No	No	No	No	No	

NC = no correction, static GPS; RTDC = real-time differential correction; PPDC = post-processing differential correction; MM = map matching (to overlap potentially incongruent GPS collected data and GIS maps).

TABLE B6
DATA STORAGE MEDIA AND SHARING PROCEDURES

Area of Expertise	State	Data Storage Media	How Are Electronic Files Stored?	How Is PMS Data Stored Over Time?	How Is PMS Information Shared?	PMS apps Web-Enabled?
PMS & GIS	AK	E	MID	STR	UR/IA	Internet
GIS	AK	E	ID	STR	UR/PR/IA	Internet
PMS	AL	E/P	ID	STR	PR	No
GIS	AL	E	MID	STR	UR	Intranet
PMS	AR	E	FF/TF/RDR	STR	UR/PR	
PMS	AZ	E	MID/RDR/RCR	STR	UR/PR/IA	No
PMS	BC	E	MID/RCR	STR	UR/PR/IA	
PMS & GIS	CA	E	FF/TF/ID	STR	O	No
PMS	CO	E	RDR	STR	UR	
GIS	CO	E	RCR/CD	NS	UR/PR/IA	Internet
PMS & GIS	CT	E/P	FF/TF/MID/RCR	NCD	UR/PR	No
PMS	DE	E	NS	STR	UR	
PMS	FL	E	CD	NCD	PR/IA	
PMS	GA	E	RCR/CD	STR	UR	No
GIS	HI	E/P	MID	STR	Other: Intranet to agency only	
PMS	IA	E	ID	NCD	UR/PR	Intranet
PMS & GIS	IA	E	MID/RDR	NCD	UR	Intranet
PMS	ID	E	FF/TF	STR	UR/PR/IA	
GIS	ID	E	FF/TF	STR	UR/PR	
PMS	IL	E/P	RDR	NCD	Other: Some data are available in the internet, other available upon request.	
GIS	IL	E	CD	NCD	IA/Other: Intranet	Internet
PMS	IN	E/P	RDR		UR	
PMS & GIS	KS	E	RDR	STR	UR/PR/IA	Intranet
GIS	KS					
PMS	KY	E/P	FF/TF/ID/RDR	STR	UR/PR	
PMS	LA	E	ID	STR	UR/PR/IA	Intranet
PMS	MD	E/P	RCR	STR	UR/Other: Intranet (internal to agency)	Intranet
GIS	MD	E	RDR	NS	Other: Enterprise thick client GIS, distribution to public by pavement group only, based on their assessment of need.	
PMS	ME	E	ID	NCD	UR/Other: Maine TIDE System (Transportation Information for Decision Enhancement)...our in-house data warehouse	No
GIS	ME	E	ID/CD	NCD	UR/PR	No
PMS	MN	E	RCR/CD	STR	UR/PR/IA/Other: Local access on each district's server	No
GIS	MO	E/P	CD	STR	UR/PR/IA/Other: Enterprise canned reports	No
PMS	MS	E	FF/TF/RCR		UR/PR	No
GIS	MT	P		NCD	UR/PR/IA/O	Internet
PMS	MT	E/P	FF/TF/RCR	STR	UR/PR/Other: Intranet	
PMS	N.B.	E/P	MID	NCD	UR/PR/Other: Shared Directory	
PMS	NC	E	MID/RDR	STR	UR/IA	Internet
PMS	ND	E/P	RCR	NCD	UR/PR/Other: Mainframe	No
PMS	NE	E	RCR	NCD	UR/IA	Intranet
PMS	NH	E	RDR	NCD	UR/PR/IA	Internet
PMS	NJ	E	ID/MID/RCR	NCD	UR/PR	No
GIS	NJ	E	RCR	STR	UR	No
PMS	NL	E/P	FF/TF	STR	UR/PR	
PMS	NM	E	ID	STR	UR	
PMS	NV	Other: (1)		STR	UR/PR/Other: Internet Accessibility (hopefully this year for agency use)	No

PMS & GIS	NY	E	ID	STR	UR/PR/Other: Server access (LAN)	No
PMS	OH	E	CD	STR	Other: Network	No
GIS	OH	E	RCR	NS	Other: Online query tools	Intranet
PMS	OK	E	ID	STR	UR/PR	
PMS & GIS	OK	E	CD	STR	Other: Intranet to the agency, available on request to public	Intranet
PMS	OR	E	RCR	NCD	UR/IA	
PMS	PA	E	RDR	STR	Other: Mainframe	
GIS	PA	E	FF/TF	NS	UR/PR/Other: Geospatial database	Intranet
GIS	PEI	E	ID	NCD	UR	
PMS	RI	E	ID	NCD	UR	Intranet
PMS	SC	E	ID	NCD	UR/PR	No
PMS	SD	E	ID	STR	UR/PR	No
PMS	SD	E	RCR	STR	UR/PR	No
PMS	TN	E	MID	STR	UR/PR/Other: Intranet	
GIS	TN	E	ID	NS	Other: PMS system and via the TRIMS application on our network	No
PMS	TX	E	ID	STR	UR/PR/Other: We have developed a data download program in Microsoft Access that TxDOT employees can use to download, report, and map data.	Intranet
PMS & GIS	TX	E	CD	STR	Other: Mainframe connection	No
PMS	UT	E	ID	NCD	UR	
PMS & GIS	UT	E	RDR/RCR/CD	NS	Other: Not shared	Intranet
PMS & GIS	VA	E	FF/TF/MID/RDR/RCR/CD	NCD	UR/PR/IA	No
GIS	VA	E	RCR	NS	IA	
PMS	VT	E	RCR	STR	UR/PR/IA	No
PMS & GIS	VT	E	RCR	STR	UR/PR/Other: Via GIS data repository	No
PMS & GIS	WA	E	RCR	STR	UR/IA	No
GIS	WA	E	RCR	NS	UR	No
PMS & GIS	WI	Video records		STR	UR/PR	No
PMS	WV	E/P	FF/TF	NCD	UR/IA	
PMS	WY	E	RCR	STR	UR/PR	

E = electronic files; P = paper files; E/P = both electronic and paper files; FF = flat files; TF = text files; ID = one independent database; MID = more than one independent database; RDR = related databases with different referencing methods; RCR = related databases with a consistent referencing method; CD = central enterprise-wide database; NS = not sure; STR = PMS stores sequential temporal records; NCD = data are replaced by newly collected data and the data are periodically archived; UR = available upon request; PR = printed report; IA = Internet accessible; O = other; Internet = yes, Internet enabled; Intranet = yes, but only intranet enabled; No = no, there is not web access.

(1) We are currently moving all PMS files from 2002 to 1992 to Oracle. Then we will move 1980 to 1991. Once these data have been moved from either the main frame or server and verified in Oracle we will no longer have paper files. In addition, we will be switching to Adobe for report generation on the web rather than printing year end reports.

TABLE B7
LOCATION REFERENCING SYSTEMS USED FOR PMS

Area of Expertise	State	Type of Referencing Systems	Linear Referencing Systems	Other	Area Referencing Systems
PMS & GIS	AK	Linear	RL/LM/LAT		
GIS	AK	Linear	RL/LAT		
PMS	AL	Linear	RL/LAT/SP		
GIS	AL	Linear	RL/LAT		
PMS	AR	Linear	RL		
PMS	AZ	Linear	RL/LAT		
PMS	BC	Linear	RL		
PMS & GIS	CA	Linear	RL/LM/SP		
PMS	CO	Linear	RL		
GIS	CO	Linear	RL		
PMS & GIS	CT	Linear	RL/LAT/SP		
PMS	DE	Linear	RL		
PMS	FL	Linear	RL		
PMS	GA	Linear	RL		
GIS	HI	Linear	RL		
PMS	IA	Linear	RL/LM/LAT		
PMS & GIS	IA	Linear/Area	RL/LAT		CO
PMS	ID	Linear	RL		
GIS	ID	Linear	RL		
PMS	IL	Linear	RL		
GIS	IL	Linear	SP		
PMS	IN	Linear	RL		
PMS & GIS	KS	Linear/Area	RL/LM/LAT		RE/DI/CO
GIS	KS				
PMS	KY	Linear	RL		
PMS	LA	Linear	RL		
PMS	MD	Linear	RL/LAT		
GIS	MD	Linear	RL/LAT		
PMS	ME	Linear	RL/LM		
GIS	ME	Linear	Other	Superlinks—modified link/node	
PMS	MN	Linear	RL/SP		
GIS	MO	Linear	RL		RE/DI/CO/CI
PMS	MS	Linear	RL		
GIS	MT	Linear	RL/LM/LAT/SP/Other		
PMS	MT	Linear	RL/SP		
PMS	N.B.	Linear	Other	Route, Control Section, Kilometer	
PMS	NC	Linear	RL		CO
PMS	ND	Linear	RL/LAT/SP		
PMS	NE	Linear	RL/LAT		
PMS	NH	Linear	RL		
PMS	NJ	Linear	RL/LAT		
GIS	NJ	Linear	RL		

PMS	NL	Linear	RL		
PMS	NM	Linear			
PMS	NV	Linear/Area	RL/LAT		RE/DI/CO
PMS & GIS	NY	Linear	RL/LM/LAT/SP		
PMS	OH	Linear	RL		
GIS	OH	Linear	RL		
PMS	OK	Linear	RL/LAT		
PMS & GIS	OK	Linear	RL/LAT		
PMS	OR	Linear	RL/LM		
PMS	PA	Linear	RL/LAT		
GIS	PA	Linear	Other	Route Cumulative Distance	
GIS	PEI	Linear	Other	Route Section Offset Chainage	
PMS	RI	Linear	RL/LAT		
PMS	SC	Linear	RL		
PMS	SD	Linear	RL		
PMS	SD	Linear	RL		
PMS	TN	Linear	RL		
GIS	TN	Linear	RL		
PMS	TX	Linear	RL/LAT		
PMS & GIS	TX	Linear	RL		
PMS	UT	Linear	RL		
PMS & GIS	UT	Linear	RL		
PMS & GIS	VA	Linear	RL/LM/LAT		
GIS	VA	Linear	RL/LAT		
PMS	VT	Linear	RL		
PMS & GIS	VT	Linear	RL		
PMS & GIS	WA	Linear/Area	RL		RE/DI/CO
GIS	WA	Linear	RL		
PMS & GIS	WI	Linear	Other	Link Node	
PMS	WV	Linear	RL/LAT		
PMS	WY	Linear	RL		

RL = route and log point; LM = landmark; LAT = latitude/longitude (GPS); SP = state plane or other coordinate system; RE = region; DI = district; CO = county; CI = city

TABLE B8
GIS DEVELOPMENT APPROACH

Area of Expertise	State	Describe PMS/GIS Development Approach	Rate Agency-Wide Effort Approach	Rate Individual Effort Approach	Rate Other Approach
PMS & GIS	AK	An individual effort of the PMS group		Recommended	
GIS	AK	An individual effort of the PMS group			
PMS	AL	Don't Know			
GIS	AL	Part of an agency-wide effort	Recommended		
PMS	AR				
PMS	AZ	An individual effort of the PMS group			
PMS	BC				
PMS & GIS	CA	An individual effort of the PMS group		Not Recommended	
PMS	CO				
GIS	CO	Part of an agency-wide effort	Recommended		
PMS & GIS	CT	Don't Know			
PMS	DE				
PMS	FL				
PMS	GA	Part of an agency-wide effort	Recommended		
GIS	HI	Other: Individual part of other group			Not Recommended
PMS	IA	Don't Know			
PMS & GIS	IA	Part of an agency-wide effort	Recommended		
PMS	ID				
GIS	ID				
PMS	IL	Don't Know			
GIS	IL	Part of an agency-wide effort	Recommended		
PMS	IN				
PMS & GIS	KS	An individual effort of the PMS group		Recommended	
GIS	KS	Part of an agency-wide effort			
PMS	KY				
PMS	LA	Other: Assign to data bank or GIS group			Recommended
PMS	MD	Part of an agency-wide effort			
GIS	MD	Other: (1)			
PMS	ME	Part of an agency-wide effort	Recommended		
GIS	ME	Part of an agency-wide effort	Recommended		
PMS	MN	An individual effort of the PMS group			
GIS	MO	Part of an agency-wide effort	Recommended		
PMS	MS	Part of an agency-wide effort			
GIS	MT	Part of an agency-wide effort			
PMS	MT				
PMS	N.B.				
PMS	NC	Part of an agency-wide effort	Recommended		
PMS	ND	Part of an agency-wide effort			
PMS	NE	Part of an agency-wide effort	Recommended		
PMS	NH	An individual effort of the PMS group			
PMS	NJ	Part of an agency-wide effort	Recommended		
GIS	NJ	Part of an agency-wide effort			

PMS	NL				
PMS	NM				
PMS	NV	Part of an agency-wide effort	Recommended		
PMS & GIS	NY	Part of an agency-wide effort	Recommended		
PMS	OH	An individual effort of the PMS group		Recommended	
GIS	OH	Part of an agency-wide effort			
PMS	OK				
PMS & GIS	OK	Other: (2)			Recommended
PMS	OR				
PMS	PA				
GIS	PA	Other: (3)			Recommended
GIS	PEI				
PMS	RI	Part of an agency-wide effort	Recommended		
PMS	SC	Don't Know			
PMS	SD	Don't Know			
PMS	SD	Part of an agency-wide effort	Recommended		
PMS	TN				
GIS	TN	An individual effort of the PMS group		Not Recommended	
PMS	TX	An individual effort of the PMS group		Recommended	
PMS & GIS	TX	An individual effort of the PMS group		Not Recommended	
PMS	UT				
PMS & GIS	UT	An individual effort of the PMS group		Recommended	
PMS & GIS	VA	Part of an agency-wide effort	Recommended		
GIS	VA	Part of an agency-wide effort	Recommended		
PMS	VT	Part of an agency-wide effort	Recommended		
PMS & GIS	VT	Other: (4)			Recommended
PMS & GIS	WA	Part of an agency-wide effort	Recommended		
GIS	WA	Part of an agency-wide effort			
PMS & GIS	WI	An individual effort of the PMS group		Not Recommended	
PMS	WV				
PMS	WY				

(1) Pavement is part of enterprise GIS application. Pavement also has their own apps including more extensive data.
(2) PMS and GIS teams developed the approach to make PMS data part of enterprise-wide data source for all agency employees.
(3) Geospatial techs leading small group of forward thinking PMS staff.
(4) An individual effort of the PMS group to develop the PMS as needed, but a recognition that it is also part of an agency-wide effort to integrate data.

TABLE B9
GIS TECHNOLOGY USED

Area of Expertise	State	What GIS Software Do You Use?	Rate Software				
			User Friendliness	Learning Curve	Technical Support	Flexibility	Functionality
PMS & GIS	AK	ESRI	Satisfied	Neutral	Neutral	Satisfied	Satisfied
GIS	AK	ESRI	Neutral	Satisfied	Dissatisfied	Satisfied	Neutral
PMS	AL	Intergraph/ESRI	Neutral	Neutral	Neutral	Neutral	Neutral
GIS	AL	ESRI	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
PMS	AR						
PMS	AZ	Other	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
PMS	BC						
PMS & GIS	CA	ESRI	Neutral	Neutral	Neutral	Neutral	Neutral
PMS	CO						
GIS	CO	ESRI	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
PMS & GIS	CT						
PMS	DE						
PMS	FL						
PMS	GA	ESRI					
GIS	HI						
PMS	IA	Intergraph/ESRI					
PMS & GIS	IA	Intergraph/Other: Oracle, MicroStation	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
PMS	ID						
GIS	ID						
PMS	IL						
GIS	IL	ESRI	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
PMS	IN						
PMS & GIS	KS	Intergraph/Other: Write our own	Neutral	Neutral	Neutral	Neutral	Neutral
GIS	KS	Intergraph	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
PMS	KY						
PMS	LA	Intergraph/ESRI	Neutral	Neutral	Neutral	Neutral	Neutral
PMS	MD	ESRI	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
GIS	MD	ESRI					
PMS	ME	ESRI	Dissatisfied	Dissatisfied	Neutral	Neutral	Dissatisfied
GIS	ME	ESRI	Neutral	Neutral	Dissatisfied	Neutral	Neutral
PMS	MN	ESRI	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
GIS	MO	ESRI					
PMS	MS	Intergraph	Neutral	Neutral	Neutral	Dissatisfied	Neutral
GIS	MT	ESRI	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
PMS	MT						
PMS	N.B						
PMS	NC	ESRI	Satisfied	Neutral	Neutral	Satisfied	Neutral
PMS	ND	ESRI	Neutral	Neutral	Neutral	Neutral	Neutral
PMS	NE	Intergraph	Neutral	Neutral	Neutral	Neutral	Neutral
PMS	NH	ESRI	Neutral	Dissatisfied	Neutral	Neutral	Neutral
PMS	NJ	Intergraph	Neutral	Neutral	Neutral	Neutral	Neutral
GIS	NJ	Intergraph/ESRI/Bentley	Neutral	Neutral	Satisfied	Satisfied	Satisfied
PMS	NL						
PMS	NM						
PMS	NV	Intergraph	Neutral	Neutral	Neutral	Neutral	Neutral
PMS & GIS	NY	ESRI	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
PMS	OH	Intergraph	Neutral	Neutral	Neutral	Neutral	Neutral
GIS	OH	Intergraph	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
PMS	OK						
PMS & GIS	OK	Intergraph	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
PMS	OR						
PMS	PA						
GIS	PA	Intergraph/Bentley	Neutral	Satisfied	Neutral	Satisfied	Satisfied

GIS	PEI						
PMS	RI	ESRI	Satisfied	Satisfied	Neutral	Neutral	Satisfied
PMS	SC						
PMS	SD						
PMS	SD	Intergraph	Neutral	Neutral	Neutral	Neutral	Neutral
PMS	TN						
GIS	TN	Other: (1)	Neutral	Neutral	Neutral	Neutral	Neutral
PMS	TX	ESRI	Dissatisfied	Dissatisfied	Dissatisfied	Satisfied	Dissatisfied
PMS & GIS	TX	ESRI	Satisfied	Satisfied	Neutral	Satisfied	Satisfied
PMS	UT						
PMS & GIS	UT	Intergraph/ESRI	Neutral	Neutral	Neutral	Neutral	Neutral
PMS & GIS	VA	ESRI	Satisfied	Satisfied	Neutral	Neutral	Satisfied
GIS	VA	ESRI	Satisfied	Neutral	Neutral	Satisfied	Satisfied
PMS	VT	ESRI/Other: Deighton dTIMS CT	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
PMS & GIS	VT	ESRI/Other: Deighton dTIMS CT	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
PMS & GIS	WA	ESRI	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
GIS	WA	ESRI	Satisfied	Neutral	Neutral	Neutral	Satisfied
PMS & GIS	WI	ESRI	Neutral	Neutral	Neutral	Neutral	Neutral
PMS	WV						
PMS	WY						

ESRI = ESRI family of products: ArcGIS, ArcView, ArcInfo; Intergraph = Intergraph family of products: Geomedia, MGE; MapInfo = MapInfo products; Bentley = Bentley Geographic products.

(1) No geospatial package used for PMS application, PMS database accessed by linking to other spatially enabled databases and applications.

TABLE B10
MANAGEMENT SYSTEMS THAT SHARE INFORMATION WITH THE PMS

Area of Expertise	State	Integrated with PMS via GIS?								Uses Same Referencing System as PMS?							
		BMS	AMS	SMS	CMS	PTMS	ITMS	MMS	Other	BMS	AMS	SMS	CMS	PTMS	ITMS	MMS	Other
PMS & GIS	AK																
GIS	AK																
PMS	AL																
GIS	AL																
PMS	AR																
PMS	AZ																
PMS	BC																
PMS & GIS	CA	N	N	N	N	N	N	N		Y	Y	Y	Y	Y	Y	Y	
PMS	CO																
GIS	CO	Y		Y	Y					Y		Y	Y				
PMS & GIS	CT	DN								DN				Y			
PMS	DE																
PMS	FL																
PMS	GA																
GIS	HI																
PMS	IA																
PMS & GIS	IA																
PMS	ID																
GIS	ID																
PMS	IL																
GIS	IL	Y	Y	Y	Y	N	Y	N		Y	Y	N	Y	N	Y	N	
PMS	IN																
PMS & GIS	KS		N			N			Y		N			N			N
GIS	KS																
PMS	KY																
PMS	LA	Y	Y							N	Y						
PMS	MD																
GIS	MD																
PMS	ME																
GIS	ME	Y	Y	Y			Y			Y	Y	Y			Y		
PMS	MN																
GIS	MO	Y	Y	Y			Y			Y	Y	Y			Y		
PMS	MS	Y	DN				Y			Y	Y				Y		
GIS	MT																
PMS	MT																
PMS	N.B																
PMS	NC	DN	DN	DN	DN	Y	DN		DN	Y	DN	DN	DN	Y	DN		DN
PMS	ND																
PMS	NE	Y					Y			DN					DN		
PMS	NH																
PMS	NJ										Y			Y	Y		Y
GIS	NJ																
PMS	NL																
PMS	NM																
PMS	NV		Y			N	Y				N			N	N		
PMS & GIS	NY																
PMS	OH								N								Y
GIS	OH	Y	Y	Y		Y	Y			Y	Y	Y		Y	Y		
PMS	OK																
PMS & GIS	OK	Y	Y			Y	Y		Y	N	N			Y	Y		Y
PMS	OR																
PMS	PA																
GIS	PA	Y				Y	Y		Y	Y				Y	Y		Y
GIS	PEI																
PMS	RI																
PMS	SC		N						N		Y						Y
PMS	SD																
PMS	SD	N							N	Y							Y
PMS	TN																
GIS	TN								N								Y
PMS	TX																

PMS & GIS	TX																
PMS	UT																
PMS & GIS	UT																
PMS & GIS	VA	N	N			N				N	N			N			
GIS	VA	Y	Y	Y		Y				Y	Y	Y		Y			
PMS	VT																
PMS & GIS	VT	Y	Y			Y	Y			Y	Y	Y		Y	Y		
PMS & GIS	WA																
GIS	WA																
PMS & GIS	WI		Y								Y						
PMS	WV																
PMS	WY																

Management Systems:

BMS = bridge; SMS = highway safety; CMS = traffic congestion; PTMS = public transportation facilities and equipment; ITMS = intermodal transportation facilities and systems; MMS = maintenance management; AMS = asset management.

N = no; Y = yes; DN = don't know.

TABLE B11
MANAGEMENT SYSTEMS PLANNING TO SHARE INFORMATION WITH THE PMS

Area of Expertise	State	Plan to Integrate with PMS via GIS?								Plan to Use Same Referencing System as PMS?							
		BMS	AMS	SMS	CMS	PTMS	ITMS	MMS	Other	BMS	AMS	SMS	CMS	PTMS	ITMS	MMS	Other
PMS & GIS	AK																
GIS	AK							DN								DN	
PMS	AL	DN	Y					DN		N	Y					Y	
GIS	AL	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	
PMS	AR																
PMS	AZ																
PMS	BC																
PMS & GIS	CA	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	
PMS	CO																
GIS	CO																
PMS & GIS	CT	Y						DN		DN						Y	
PMS	DE																
PMS	FL							Y									
PMS	GA	Y	Y	Y				Y		Y	Y	Y				Y	
GIS	HI																
PMS	IA																
PMS & GIS	IA	Y	Y	Y				Y		N	N	N				Y	
PMS	ID		Y		Y	Y	Y	Y			Y		Y	Y	Y	Y	
GIS	ID	Y	DN	Y	Y	Y		Y		Y	DN	N	Y	Y		Y	
PMS	IL																
GIS	IL							Y								Yes	
PMS	IN																
PMS & GIS	KS																
GIS	KS																
PMS	KY	N	Y					Y		Y	Y					Y	
PMS	LA	Y	Y	Y				Y		N	Y	Y				Y	
PMS	MD		N								Y						
GIS	MD																
PMS	ME	Y	DN							N	DN						
GIS	ME																
PMS	MN																
GIS	MO	Y	Y	Y	Y					Y	Y	Y	Y				
PMS	MS																
GIS	MT																
PMS	MT							N								Y	
PMS	N.B																
PMS	NC																
PMS	ND																
PMS	NE																
PMS	NH																
PMS	NJ	Y	Y	Y	Y			Y		Y	Y	Y	Y			Y	
GIS	NJ	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	
PMS	NL	Y								Y							
PMS	NM	DN	DN	DN	DN	DN	DN	DN		DN	DN	DN	DN	DN	DN	DN	
PMS	NV																
PMS & GIS	NY	Y		Y				Y		N		Y				N	
PMS	OH																
GIS	OH	Y		Y	Y			Y		Y		Y	Y			Y	
PMS	OK																
PMS & GIS	OK																
PMS	OR																
PMS	PA																
GIS	PA																
GIS	PEI		Y	N							Y	Y					
PMS	RI																
PMS	SC	DN	DN							Y	Y						
PMS	SD																
PMS	SD		DN						DN		Y						Y
PMS	TN	DN	DN					DN		Y	DN					Y	
GIS	TN																
PMS	TX							Y								N	

PMS & GIS	TX																
PMS	UT																
PMS & GIS	UT	N	Y	Y	N			Y		N	Y	Y	Y			Y	
PMS & GIS	VA	Y	Y					Y		N	N					N	
GIS	VA	Y	Y		Y			Y		Y	Y		Y			Y	
PMS	VT	Y	Y	Y	Y			Y		Y	Y	Y	Y			Y	
PMS & GIS	VT	Y	Y	Y	Y			Y		Y	Y	Y	Y			Y	
PMS & GIS	WA							N								Y	
GIS	WA							DN									
PMS & GIS	WI																
PMS	WV	DN								Y							
PMS	WY	Y	Y	Y						Y	Y	Y					

Management Systems:

BMS = bridge; SMS = highway safety; CMS = traffic congestion; PTMS = public transportation facilities and equipment; ITMS = intermodal transportation facilities and systems; MMS = maintenance management; AMS = asset management.

N = no; Y = yes; DN = don’t know.

Abbreviations used without definition in TRB Publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
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
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation