Iowa Pavement Management Program Database: Integration and Delivery

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Iowa has embarked on a project to develop a statewide pavement management system (PMS). The project, the Iowa Pavement Management Program (IPMP) covers 38,000 km (23,500 miles) of roads operated under three levels of government including state, county, and city. The mission of the project is to support both project-level and network-level PMS conducted by cities, counties, regional planning affiliations (RPAs), metropolitan planning organizations (MPOs), and the Iowa Department of Transportation (Iowa DOT). This paper will discuss issues related to the integration of the different data elements of the PMS, data exchange, and data delivery. It will also focus on institutional issues that had to be overcome for the successful implementation of the IPMP.

The IPMP database was developed in a geographic information system (GIS) environment to facilitate data integration and to support easier access and use of information. The IPMP GIS database utilizes dynamic segmentation, which further enables data integration and facilitates data maintenance and update.

The IPMP database integrates all of the PMS data and creates an environment by which the users can make informed decisions regarding their pavement maintenance, rehabilitation, or reconstruction. The database includes all of the inventory, history, and condition information referenced to a graphical interface, which allows the user to obtain data for any highway or street segment. This paper will discuss the methodology used to accomplish this objective.

PMS data delivery is of great importance to the success of the implementation process. Local and regional governmental agencies using the IPMP data need an efficient and simple tool to access the PMS database. As part of the project, a delivery mechanism was developed to allow users access to the IPMP database through an easy to use GIS interface. This paper will focus on the issues considered and also on the final design for the data delivery mechanism.

INTRODUCTION

The Iowa Pavement Management Program (IPMP) is a coordinated effort to develop a statewide comprehensive pavement management system (PMS) for all of the federal aid eligible highways in the state. The Iowa Department of Transportation (Iowa DOT), cities, and counties are participating in the development, implementation, and operation of the IPMP.

The IPMP database covers 38,000 km (23,500 miles) of roads under the three levels of governments (Iowa DOT, cities, and counties) and it supports their needs for pavement management information, tools, and database. The mission of the IPMP is to support both project-level and network-level PMS conducted by individual cities, counties, regional planning affiliations (RPAs), metropolitan planning organizations (MPOs), and the Iowa DOT by providing those governmental agencies with the necessary pavement management information.

The IPMP divided the activities required to support pavement management into four fundamental elements. The following is a brief description of each activity.

- Construct a database of data elements needed to conduct pavement management analysis (data integration).
- Collect pavement history and condition data to populate the pavement management database.

- Make available the decision support tools to conduct pavement management at each level of government (local, regional, or statewide).
- Make pavement condition, history and inventory data, and pavement management system parameters available to individual jurisdictions (data delivery)

With these four elements, Iowa governmental agencies may perform pavement management within their own jurisdictions. This paper focuses on both the data integration and data delivery issues related to the IPMP.

Because of the scale and the large number of jurisdictions involved in the development of the IPMP, the planning, design, and development process had to consider institutional issues. To over come the institutional issues, representatives from all the involved governments and the Federal Highway Administration formed a non-NHS task force to direct the planning, development, and implementation of the IPMP. Early in the development of the IPMP, while the mission, goals, and objectives were being developed and while plans were being developed, the task force met about once a month. So far, the task force has established three committees to supervise major tasks. The data collection committee is responsible for the evaluation and selection of an automated distress vendor to collect pavement distress data. The database committee is responsible for the development of the IPMP geographic information system (GIS) database. Finally, the pavement management software committee is responsible for the evaluation, selection, and calibration of the pavement management tools selected for the IPMP.

IPMP DATABASE BACKGROUND

A primary function of the IPMP database is to integrate the multiple data sets required for pavement management, specifically pavement history and condition (distress) data, while limiting data redundancy and facilitating data maintenance and analysis. In addition, the IPMP database should provide an environment by which users can make informed decisions regarding their pavement maintenance, rehabilitation, and reconstruction. These functions are served by a geographic information system (GIS) with dynamic segmentation capabilities.

GIS provides the ability to capture, store, manage, retrieve, query, analyze, and present spatial data, such as the location of a pavement management section or specific distresses along a roadway. GIS also provides a common environment for all pavement management data, both graphic and attribute, to be maintained. The addition of dynamic segmentation capabilities within GIS further enhances its data integration functionality, allowing the overlay and display of attributes along the linear (highway) network. This section focuses on the data comprising the IPMP database and how GIS and dynamic segmentation are utilized to integrate these data for pavement management.

IPMP Data Components

The IPMP database consists of four primary data components: roadway cartography and inventory data provided by the Iowa Department of Transportation (DOT), pavement history data provided by the Iowa DOT and local agencies, and pavement distress data collected centrally utilizing automated distress collection equipment.

Roadway Inventory

The Base Record Inventory System is the DOT's comprehensive inventory of the roadway system, containing information about all roads and structures within the State. The roadway portion of the Base Record Inventory System contains over 150 attributes describing the roadway. New segments are created where changes in attribute values occur. Only selected attributes that apply to pavement management are included in the IPMP database, such as pavement length, pavement width, average annual daily traffic, route (street) name, surface type, shoulder rating, surface rating, drainage rating, jurisdiction, traffic year, traffic profile, speed limit, and number of rehabilitations.

Roadway Cartography

The Iowa DOT's roadway cartography provides a graphic representation of Iowa's roadway system. A one-to-one relationship exists between roadway cartographic elements and records in the Base Record Inventory System. Through use of GIS, the inventory record corresponding to a given graphic representation of a roadway can be accessed.

Pavement History

Pavement history data are specific to pavement management sections. Section limits are determined by identifying the location of changes in pavement surface type, project history, traffic volumes and composition, functional classification, or the occurrence of jurisdictional boundaries. Sections average in length from approximately 0.5 kilometers in urban areas to 3.5 to 10 kilometers in rural areas. Data provided for each pavement management section includes surface type (original, additional rehabilitation, and most recent), pavement thickness (original, additional rehabilitation, most recent, and total), and construction/rehabilitation cost (most recent).

Pavement Condition

Pavement condition (distress) data are collected through an automated mechanism, specifically, an ARAN van from *Roadware Corporation*. The ARAN van collects and stores video images of the pavement surface that are digitized and processed using pattern recognition software to identify, quantify and classify each distress. Rutting and roughness (IRI) are collected real time (speeds of up to 90 km/h) while collecting the rest of the surface distresses. Pavement distress data, which include cracking, potholes, patches, rutting, and ride, are collected and aggregated to linear segments of one hundred meters in length in both urban and rural areas. A global positioning system (GPS) receiver collects the geographic coordinates of the vehicle's position at each reading. These coordinates are differentially corrected (accurate within three to ten meters) and used to denote the endpoints of each 100-meter, linear segment.

IPMP Database Tools

The aforementioned IPMP data sets describe, or in the case of cartography represent, specific segments (sections) of the highway network. However, attributes, segment extents and locations, and location descriptions are data specific, making data integration difficult. GIS with dynamic segmentation capabilities provides the tools necessary to better facilitate data integration.

Geographic Information System (GIS)

A geographic information system (GIS) is a computerized database management system for storing, managing, retrieving, querying, analyzing, and presenting spatial data. GIS contains two types of information, spatial data and attribute data. Spatial data define line, point, or polygon objects (elements) located on the surface of the earth. Information associated with these objects is stored in attribute tables.

A traditional GIS database, without dynamic segmentation capabilities, is somewhat limited in its ability to manage and present multiple data sets describing a single feature, such as a highway. A common method to manage such data is to maintain all data sets in a single database table. New records, and corresponding graphic elements, are created where attribute values change, such as pavement type. All data sets are reduced to their least common denominator, resulting in a significant amount of attribute data redundancy. The Base Record Inventory System is maintained in this manner.

Another potential method to manage such data sets is to maintain each attribute table separately. A one-to-one relationship between attribute records and graphic elements must be maintained within the GIS, resulting in network (graphic) redundancy. This redundancy may be reduced if all attribute records, in all attribute tables, share the same linear extents. Multiple attribute records can then share the same graphic representation. This, however, limits flexibility in data collection and maintenance. A final method, which is certainly the most robust, is dynamic segmentation.

Dynamic Segmentation

As noted previously, dynamic segmentation is the overlay and display of attributes describing a linear referenced highway network. Dynamic segmentation can accommodate multiple attribute tables, describing a highway network, without requiring duplication of network geometry or data. Only a single, graphic representation of the highway network is required. The locations of attribute records along the highway network are identified using a linear referencing method.

Components of a linear referencing method include identification of a route organization scheme and measurement of a distance and direction from a known point. Common linear referencing methods are base point (offset) and control point. The base point (offset) method references all locations based on their distance (along a route) from the route origin. Linear features located longitudinally along a route may be referenced using begin and end distances from the route origin or begin distance from the origin and length. The control point method references all locations based on known locations (markers) along a route, such as milepost signs. Positive or negative offsets from these known markers may be used to reference locations.

The spatial nature of GIS also enables the use of spatial referencing methods to identify the location of attribute data. In other words, coordinates identify the location of a point or linear extent along a highway. These coordinates may be either geographic (i.e. longitude, latitude) or projected (e.g. State Plane).

The flexibility of dynamic segmentation, with respect to data collection, management, and integration, was the primary reason it was selected for the IPMP database. The various IPMP data components are provided by different sources, collected independently using specific methodologies, and referenced to the highway network using different methods. Without dynamic segmentation, rigid constraints on data collection and referencing procedures would be necessary to ensure data compatibility. Applying such constraints may not only be impractical but also limit the ability of dynamic segmentation to facilitate data collection in the most logical manner. Moreover, such constraints complicate the redefinition of segment limits (e.g. changing the beginning and ending locations of a segment). The temporal nature of the IPMP data warrants flexibility in segment definition. Dynamic segmentation allows segments to be defined freely without impacting, or being impacted by, other highway attribute data.

IPMP DATA INTEGRATION

Data integration consists of two distinct processes: development and maintenance of the underlying GIS database (built on Intergraph's MGE software, including the Segment Manager module, Bentley's MicroStation, and Oracle) and analysis of the IPMP data, including production of the data sets necessary for pavement management (optimization software). Data integration is an ongoing process, dependent on both changes in the underlying data as well as analysis needs.

GIS Database

Highway Network

The primary components of the GIS database are a base, linearly referenced (highway) network and attribute tables, roadway inventory, pavement history, and pavement condition (distress), describing the highway network. Together, the Iowa DOT's roadway cartography and inventory data provide the foundation for the IPMP database. They form the base linear (highway) network required by GIS to perform dynamic segmentation, and, ultimately, produce the data necessary for pavement management, i.e. combined pavement history and condition (distress) data.

The base, linear referenced highway network consists of graphic elements representing the highway network and associated database records describing the location of each element along a route. The appropriate signed route, or street name, for each graphic element is defined by attributes from the Base Record Inventory System. The location of a graphic element along a route (street) is referenced using the base point (offset) method. The distance of the element from the beginning of a route (street) is calculated using attribute data contained in the Base Record Inventory System, including preceding element lengths. Jurisdictional boundaries, e.g. county lines and city limits, define the beginning of a route (street).

Therefore, the only attribute data required for the base highway network are route (street) designation, jurisdictional identifier, location along the route (with respect to the beginning of the route), and length. It is important to note that creation of this network would require substantially more effort if the relationship between cartography and the Base Record Inventory System did not exist.

Attribute Data

Attribute tables contained in the IPMP database must be compatible with the base, linear network. Specifically, they must include a common route designation scheme, a jurisdictional identifier (optional), and use either a linear referencing method consistent with the base point (offset) referencing method or spatial referencing. The jurisdictional identifier simply eliminates potential location ambiguity, such as 1st Street being located in multiple communities. The selected Base Record Inventory attributes are referenced to the base highway network using the same controls as the base network itself. This is because the base network was established using inventory data.

The locations of pavement history sections are identified using a route designator, jurisdictional identifier, and spatial (geographic) coordinates. Original pavement history data from the local highway operating agencies describe section limits using literal description only. However, since dynamic segmentation can not interpret literal description, GIS is used to identify the geographic coordinates (longitude, latitude) of the endpoints of each section. The derived coordinate endpoints are then included as additional attribute data. Although provided, a jurisdictional identifier is unnecessary when locations are referenced using spatial coordinates. The coordinate data themselves, in conjunction with the route designation, are all that are necessary to eliminate location ambiguity.

Pavement condition (distress) data are also referenced using a route designator, jurisdictional identifier, and spatial (geographic) coordinates. As pavement condition (distress) data are collected, the route (street) name and jurisdiction of the roadway are noted by the test vehicle operator(s). As testing begins on a new route or a new jurisdiction, this information is entered and the attributes are updated. Differential GPS (DGPS) coordinates (longitude/latitude) define the 100 meter long segments. Once again, the jurisdictional identifier is not required.

Upon establishing the base highway network and ensuring data compatibility, GIS and dynamic segmentation may be used to analyze and integrate the IPMP data.

Data Analysis

Dynamic segmentation provides for a wide array of data analysis and integration possibilities. These possibilities range from simply displaying the locations of pavement management sections to aggregating, or disaggregating, pavement history and condition data in a common table, which is the focus of the IPMP.

Data aggregation, or disaggregation, is accomplished through dynamic segmentation's advanced spatial overlay capabilities. In its most basic application, records satisfying a specific attribute query, such as all pavement history sections with an asphalt surface type, are identified, and the location of the resulting segments are located along the highway network (overlaid on the network) and displayed graphically within GIS. Advanced spatial overlay operations combine and display the results of multiple attribute table queries.

The database records resulting from spatial overlay operations may be updated in various manners. Attribute fields may be updated using several different computation functions, such as equal, average, sum, minimum, maximum, mode, count, concatenation, as well as several reference functions. Reference functions primarily relate to the base highway network, specifically the attributes that describe a location along the network (e.g. route identifier, begin distance, length, etc.).

An objective of data analysis is aggregating pavement history and condition (distress) data for use in pavement management software. Therefore, the most common data integration activities performed using dynamic segmentation and spatial overlays are updating pavement history records with pavement distress data, using computation functions, and updating pavement distress records with pavement history attributes. Of these activities, the first receives the most effort because of the resulting data usefulness in pavement management software. In brief, a spatial intersection of the pavement history and pavement distress records is performed, and distress data aggregated to the appropriate history section using established data transformation rules. Data transformation rules must be established for each data item to allow for consistent analysis of the data. If we consider rutting (a safety related item), the aggregation rule is to calculate the maximum rut depth from all test sections within each pavement management section. The value calculated is assigned to the pavement management section rut depth and represents the worst rut depth along that section. If we consider ride data (an indicator of pavement roughness), the aggregation rule is to calculate the maximum ride values as well as average ride values from all test sections within each pavement management section. However, a condition is applied to the data transformation rule: all test segments occurring on a bridge or railroad crossing are not considered in the calculations because they provide inaccurate readings. When aggregating the pavement management sections data, the average and sum are used in most cases.

Pavement distress records are updated with pavement history attributes for the sole purpose of performing advanced statistical analysis on the distress data. Once again, a spatial intersection of the pavement history and pavement distress records is performed, but the distress records are updated with the appropriate pavement management section identifier(s) from the history table. Unupdated distress records represent test sections that overlay multiple pavement management sections. This information can be used to further refine (apply conditions to) the data transformation rules previously discussed. For example, all distress records without a history section identifier could be eliminated from calculations, ensuring that only test sections occurring entirely within a pavement management section are considered.

Although integration of pavement history and distress data is a critical component of the IPMP, dynamic segmentation can be used for many other analysis purposes. For example, dynamic segmentation has proved valuable in displaying test sections with rutting values exceeding the maximum, allowable threshold and locations with very poor ride quality. The ability to perform these types of analyses, as well as work with the aggregated pavement history and distress data, are desired end user requirements. The best means by which to provide these capabilities to the end users is another important component of the IPMP.

IPMP DATA DELIVERY

A final objective of the IPMP database is to serve as an environment through which users can make informed decisions regarding pavement maintenance, rehabilitation, and reconstruction. However, IPMP users are a diverse group with varying levels of technical knowledge, software and hardware resources, and needs, with respect to access and analysis. Therefore, a primary consideration in data delivery is to ensure that all users, regardless of their software and hardware resources, will be able to utilize the data for their pavement management activities. Within this context, which data should be accessed, who should have access to the data, how should users access the data, how much experience should they have, and what types of analyses are necessary, must be considered? These considerations serve to identify the access and analysis needs of IPMP users and dictate the approaches taken to meet these needs.

Data potentially available to IPMP users includes the roadway inventory data, raw pavement distress data, and pavement distress data summarized by pavement management section. Of these data sets, the summarized distress data is the most pertinent, or applicable, to all IPMP users. To best accommodate the majority of IPMP users, the least common denominator among users, with respect to data format and distribution media, was identified as hard copy (paper) format. The summarized distress data are exported from the IPMP database, organized by jurisdiction, and distributed to the respective agencies. Unfortunately, the usefulness of the IPMP data in this format, beyond a simple reference, is minimal. Therefore, the same data are also distributed to the local agencies electronically (on diskette) in spreadsheet format. Although spreadsheet format provides for a more functional data management and analysis environment, the significant benefits provided by GIS, such as display and query capabilities do not exist. Several different approaches may be taken to provide IPMP users with these capabilities. These approaches include providing the IPMP data in GIS compatible format(s), providing both the data and tools necessary to perform the desired analyses, and providing direct access to the IPMP database. It is unlikely that one approach will accommodate all users, but it is also somewhat infeasible to support all approaches. The optimal approach, or approaches, best satisfy user requirements while limiting additional data maintenance, production, and delivery requirements.

In general, most IPMP users are interested in simply displaying the locations of their pavement management sections, interactively identifying section attributes, and creating thematic maps based on these attribute, history and distress, data. The general IPMP user does not need, nor desire, to perform dynamic segmentation. This significantly simplifies data delivery requirements. Data may be provided to users in formats that are compatible with commonly used desktop GIS software packages, many of which do not possess dynamic segmentation capabilities. All data sets, specifically the pavement distress data summarized by pavement management sections, are prepared within the IPMP database before they are provided to the end user. Since the IPMP data only covers a portion of the highway system, selected inventory data may also be necessary to provide completeness to the graphical representation of the highway (street) network. Upon preparing the necessary data sets, the data are exported from the IPMP database to a desktop GIS format, MapInfo's MapInfo Professional. MapInfo can then be used to convert the data to another desktop GIS format, ESRI's ArcView. Intergraph's GeoMedia Professional can also be used to export the IPMP data to ArcView (shape file) format. A benefit to using GeoMedia Professional is that it utilizes the IPMP GIS data in its native format, therefore eliminating a conversion step that may introduce additional error. (Third party spatial data translation software can also be used to convert the IPMP, MGE format to both the MapInfo and ArcView formats.)

Providing data in both MapInfo and ArcView formats serves more than those using these software packages and other GIS software packages that can view (Intergraph's GeoMedia and GeoMedia Professional), import, or convert these formats. It also addresses the second suggested approach, providing both the data and tools necessary to perform the desired analyses. Specifically, those not possessing compatible GIS software can utilize ESRI's free GIS data viewer, ArcExplorer, to display and query the IPMP data in ArcView format. Although it is more limited in its functionality than ArcView, ArcExplorer is user friendly and provides most of the basic capabilities desired by IPMP users and is user friendly, making it a practical tool for the inexperienced or novice user. ArcExplorer can either be downloaded from the Internet (www.esri.com) or provided as part of data delivery.

Several issues arise from providing the data in GIS compatible formats. These issues relate primarily to data preparation requirements and the distribution media. The GIS compatible data are substantially larger than the IPMP data in spreadsheet format and, in most cases, will not fit on a single diskette. This somewhat limits delivery media to CDROM. Although providing data over the Internet is an option, not all users have Internet access, and many who do still prefer receiving the data on CDROM. The question arising from distributing the data on CDROM is whether it is feasible to create a CDROM for each jurisdiction, or participating agency. By doing so, each jurisdiction would have access to their data only, in the format they desire. However, preparing the data for distribution, e.g. producing the CDROMS, would require significant effort. Additionally, using a CDROM for individual jurisdictions may be inefficient use of the media's available memory. In other words, only a small portion of the memory available will be used. As an interim solution, all data are placed on a single CDROM. The implication is that all jurisdictions will have access to each other's data.

The final data distribution option, for future consideration, is providing direct access to the IPMP database. This may be accomplished in one of two ways. First, users on the same Intranet as the IPMP database could access it directly using Intergraph's MGE or GeoMedia software. These users would be able to perform some of the more advanced querying capabilities supported by the software, but more critical examination of user access and permissions would be necessary. The other option is to develop a web application, such as Intergraph's WebMap, allowing users to access the IPMP database over the Internet. The web application could be developed in such a way as to provide users with very specific analysis capabilities, while limiting access privileges as deemed appropriate. Both of these approaches are somewhat more robust than the previously discussed in that significant effort in data production is not required. As the IPMP database is updated, these changes can be made readily available to users, without preparing and distributing new media. The user interface can be customized to meet specific user needs, taking into consideration the users' ability levels. However, developing and maintaining such a system may be somewhat more challenging.

CONCLUSIONS

The IPMP GIS database provides local governmental agencies and the Iowa DOT with an easy to use interface to all of the necessary information to conduct pavement management analysis on both the project and network level. Using the information from the IPMP, transportation agencies participating in the program will be able to access inventory, history, and condition information to be utilized for project selection and resource allocation.

The GIS database design that supports dynamic segmentation allows for flexible and efficient maintenance and update of the IPMP information. Integrating data from different sources, different location referencing methods, and different agencies becomes one of the great advantages of using the GIS database with dynamic segmentation. Data integration provides for better understanding of the overall needs of the transportation system by considering information from different management systems (safety, bridge, intermodal, etc…)

IOWA PAVEMENT MANAGEMENT PROGRAM DATABASE: INTEGRATION AND DELIVERY

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