Integrating Bridge Management Systems into the Business Process and Software Environment of the State DOT: Three States' Experiences

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ABSTRACT

The departments of transportation of California, Michigan, and Mississippi have developed general transportation management systems (TMS) that incorporate the Pontis bridge management system (BMS) developed by the American Association of State Highway and Transportation Officials. The technical and business challenges presented by these efforts have been numerous and complex: identifying the users of the systems and the data they require to do their jobs effectively; defining the database structure of the TMS; arranging for the transfer of data among the various systems with which the TMS must interact; establishing business processes and workflows; establishing ownership and responsibility for data; establishing data validation protocols; arranging for the input of data from field inspections; arranging for the integration of data that may be collected at disparate times and places. This paper will share some of the experiences of these three states, focusing on the interaction between the BMS and the other systems and processes with which it collaborates within the framework of the broader TMS.

OVERVIEW

A short list of questions was presented to each of the contributors. Their answers are intended to describe the basic structure and operation of the systems developed by their States, and to share some of the lessons learned. The commentary presented here is not intended to be technically detailed, but to serve as a starting point for further discussion.

CALIFORNIA

Who Are the Suppliers of the Information Saved in the Bridge Management Database?

The California bridge database contains all the information and images necessary to effectively manage the integrity of the bridge infrastructure. The majority of the information contained in the bridge database is supplied through our bridge inspection program. The bridge inspection teams generate all the inventory data and condition information required to comply with the National Bridge Inspection Standards (NBIS). Licensed civil engineer inspection teams also provide work recommendations, element condition information, detailed fracture critical findings, load rating information, inspection photos and commentary.

Complementing the bridge condition and inventory information, the bridge management database contains complete project tracking facilities for state crew and contract maintenance and rehabilitation work. State crew maintenance items are recommended by the inspector and when completed are flagged completed in the database by the district crew performing the work using a custom developed web page. Major rehabilitation and replacement work is typically performed under contract. The project timing, scope and status are entered and maintained by the program managers of the rehabilitation program.

California maintains a complete image archive of all bridge "as-built" plans, bridge reports, photos and other significant correspondence in the bridge database. The images are scanned and indexed into the database by a dedicated staff.

In California there are four city or county agencies that perform bridge inspections on the bridges within their jurisdiction. The information from the inspections performed by these agencies is ultimately merged into the bridge management database through file imports.

Traffic counts and other highway-related information are generated through external means and imported into the bridge database periodically.

Who Are the Clients for This Information and How Is It Used?

The bridge information entered into the database through the inspection process is ultimately is presented in a bridge inspection report. The bridge inspection report documents the current condition of the bridge and all recommended work for that structure. The bridge inspection report is the primary means of conveying the results of the inspection to the bridge owners. In addition to the bridge report, numerous list and reports are generated for district maintenance crews, project planners, Caltrans management and the California Transportation Commission.

The plans and report images contained in the bridge database are accessed online by design staff, inspectors, contractors and other interested parties. The bridge plans and reports are considered public record and access must be provided to the public. The image information may be used to review the history of a structure from a design or inspection standpoint. Contractors often review the existing bridge plans prior to submitting bids for widening projects or other "add on" type of work.

How Does the Bridge Management Database Fit into the Larger Transportation Management Database Schema?

In California the bridge management database is not formally integrated with other transportation system databases. The bridge management database itself is quite large and is accessible using many different software interfaces. There are three main applications that access some aspect of the database. The bridge inspection staff uses a custom inspection and report generation software called SMART. The bridge management staff uses the PONTIS interface to perform deterioration modeling and project prioritization The images archive is accessed using a custom developed web application called BIRIS. Many other off the shelf report writers and query tools are available for accessing the bridge management database.

Project coordination with the pavement management system is currently done through data extraction of projects from the bridge management database.

How Is the Bridge Management Information Physically Stored?

The bridge management database is stored in an Oracle 7.3 database on a SUN server operating in the UNIX environment. All bridge-related data are stored in a single database. The image archive is stored on the SUN server, but is only indexed in the database. The SUN server allows access to the bridge data using the Windows-based Oracle client via Ethernet LAN or through the Oracle Web Server using a conventional web browser. The other management systems in use within California are all designed around the Oracle database engine operating in the UNIX environment.

How Does the Information Flow from the BMS to Other Systems?

In California, the information necessary to manage the bridges is all contained in a single database. The database utilizes a shared database design (Figure 1) that eliminates the need to move information from one component to the other.

This shared database was achieved by using the Pontis data structure as the core of the bridge database. Additional tables were linked to the Pontis structure for specialized activities. Activities such as project tracking, maintenance recommendation tracking, detailed fracture critical, scour and load rating information were all linked to the Pontis structure. California has a special need for postearthquake inspection activities that were also linked to the core database structure. Photos and scanned plans are also tied into the bridge management database. The advantage of this shared database design is that information never needs to be moved to support the various client interfaces to the information.

Each software interface to the database can access only certain portions of the entire data structure. For example, the text description of the bridge condition can only be entered through the SMART application but the element inspection information is accessible through SMART and Pontis. Project information is only available in SMART while deterioration modeling is only available through Pontis. Images are accessible through the web interface of BIRIS but not through Pontis or SMART.

The overall security of the bridge management database is controlled at two levels. At the top level, all users are required to log into the Oracle engine and their privileges are set to the appropriate level. At the second level, each application that accesses the bridge data has application controls that restrict database actions. The web form used by state maintenance crews in each district is a good example of application

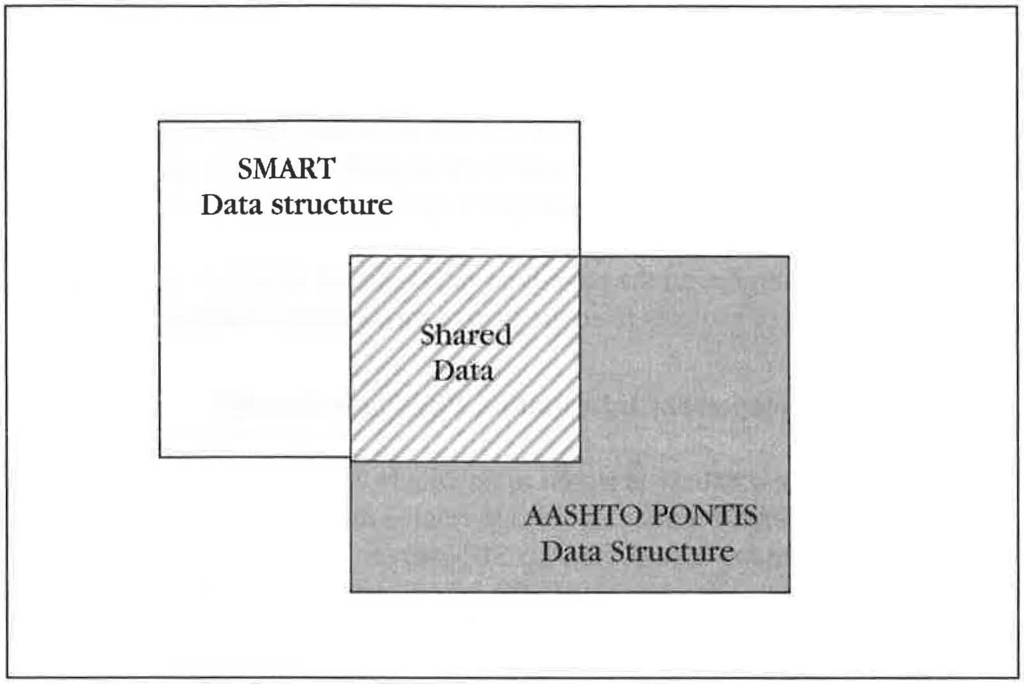

Figure 1: California's single data base sources.

restrictions. The web-based form allows remote districts maintenance crews access to current recommendations for each bridge in the state, but only allows them to update a single field that flags a work item as completed.

How Were the Decisions Made on What to Share or Not Share?

Information is shared where it is needed. In many cases the information can be seen but only modified by those with the appropriate privileges. The update of information in the bridge management database is tightly restricted to those who should be updating. Inspectors for example can update almost any data item available to them through the SMART interface but they cannot delete a bridge or inspection. The district bridge maintenance crews can only update a single item though they can view many. The intent was to open up the data as much as possible without compromising integrity.

How Does Embedding a Component in a Larger Database System Constrain the Overall System?

Having multiple applications sharing a database structure does impose some limitations on the flexibility of the system as a whole. In California we have adopted the Pontis data structure as the foundation of our bridge management database. In practical terms this means that when Pontis has a change in its database, the same change must be made in our bridge database if we want to use Pontis to access the data. Depending on the nature of the change in the Pontis database, modifications in our custom inspection application may be needed. We have tried to minimize the impacts of changes to the Pontis database by linking California-specific tables to only three of the Pontis tables. We have been fortunate that the changes made to the Pontis data structure over the past few years have been relatively minor.

California's inspection software program, SMART, shares the inspection portions of the database with the Pontis product. From a development standpoint this means that SMART must perform the same operations as Pontis when dealing with inspection-related data. For example, Pontis requires that a flag be set to tell the software that an element inspection was performed during any inspection. This flag is not used by SMART at all but must be set in order for Pontis to see any inspection input entered through SMART. Having adopted the Pontis data structure for inspection data means we adopted the good points and bad points and must perpetuate all Pontis database design features into our SMART application where the information is shared.

Data security has not been a problem using the shared database approach. Each software application has some level of security in addition to the overall Oracle database security. The one issue that we have faced with this shared data approach is uncontrolled access to the database through the open database connectivity (ODBC) standard used by Pontis. ODBC allows many common software applications such as Microsoft Access or Excel to access the contents of the Oracle database without application-level security. This uncontrolled connection allows many operations that are restricted when using Pontis or SMART. The Oracle database has the ability to shut off ODBC connections to provide a higher level of security but then Pontis product would be unable to operate.

What Have Been the Challenges and the Lessons Learned Setting Up Your System?

In the early stages of production, code or database changes are inevitable as the software evolves and expands. Controlling the version of the application in use can be a sizable task if you have a distributed user base. In the early stages of implementation we tried to have local copies of all application files residing on the clients machines. Storing the application files on each local machine led to serious version control problems. Most changes in the database structure required a revised software form to be distributed. At one point we had a small program that would copy updated files for the application to the local machine. In the long run we abandoned this approach for version control for a single server location for all the application files. I think it is important to plan how you will modify and expand your application once it is in production.

The selection of the development tool and database are two very important decisions that can affect the ultimate success of any implementation. In California we began our development using FoxPro for the development tool and found that we really couldn't scale the product up to meet the needs of a large organization. After an initial misstep, we moved to the Oracle Developer 2000 development tool for the ultimate software development. The Oracle Developer 2000 product was a good selection because it allowed the application to grow into a web-based application with minimal changes in the original client server programming.

MISSISSIPPI

How Does the Bridge Management Database Fit into the Larger Transportation Management Database Schema?

Mississippi Department of Transportation (MDOT) began development of its Transportation Management Information System (TMIS) in 1994 with the assistance of SHL Systemhouse and various subcontractors. The goal was a GIS-based system which would provide timely access to inventory data, including bridge, pavement, safety and traffic, all linked by a common linear referencing system. Since Mississippi had recently purchased the Pontis software, it was decided that we would use it as much as possible, yet maintain its database separately from the TMIS database. This way, future Pontis version changes, which were beyond our control, would not directly impact TMIS. A batch process was developed which unloads the Pontis data nightly, then uploads the data to TMIS. This provides TMIS users with bridge inspection and inventory data which is no more than one day behind. Bridge data are wholly maintained in Pontis with TMIS being view only, the only exception being a TMIS function which allows authorized users to maintain a running history of structure 'incidents.' These are events which happen during the life of the structure such as impact damage, repair or rehabilitation work, or significant studies. Users can query on incident type, estimated cost and status or review the incidents for a particular structure. Multimedia files, such as photographs, design drawings, documents, and sound files, can also be linked to a bridge in TMIS for online use.

Who Are the Suppliers of the Information That Is Saved in the Bridge Management Database?

Mississippi's Pontis database contains all the data necessary to effectively manage its bridge inventory and inspection program. Six district-based bridge inspection teams collect the majority of the data, including that required by the National Bridge Inspection Standards (NBIS). District inspectors also collect Pontis element-level condition information. Central office engineers provide additional inspection assistance for special cases and structural damage assessment. Load rating and weight restriction limits are determined by central office bridge division personnel. All information is input directly into the central database either by the inspector or bridge division personnel through the Pontis interface via a wide-area network. The Pontis database was extended with additional tables and attributes to accommodate MS-specific needs. Input of non-Pontis items is accomplished by the custom tab screens within the Pontis interface or by PowerBuilder applets developed to run within Pontis. Photographs are collected by the inspectors and forwarded to the central office. Pre-CADD design plans are currently being scanned for incorporation into the bridge management system. Traffic and road classification information required by the NBIS is generated by external means and periodically imported into the Pontis database.

Only those bridges owned and maintained by MDOT are included in the inventory. Local-, city-, and county-owned bridges are inspected and inventoried outside of MDOT's jurisdiction. Current state maintained inventory is approximately 5,320 bridges.

Who Are the Clients for This Information and How Is It Used?

The Pontis database is used primarily by District bridge inspectors and central office bridge division personnel. All other bridge information inquiry will come through TMIS once it is fully implemented in April of this year. As TMIS nears completion, usage is expected to be department-wide. With the wide array of tools available through the system, planners, designers and administrators can analyze the highway network in a myriad of ways. Anyone with a TMIS-ready computer can view the data and do queries referencing any of the subsystem data. For the first time in the history of MDOT, a user can combine bridge, pavement and traffic data in one query and within minutes have an answer. Not only are inventory and condition data available for the bridges, pavement and traffic sections, geographic and demographic data such as county and city areas and populations, state park and national forest boundaries are also included. Thematic mapping, buffer zones, query fences and dynamic map/browser interfaces allow the user to graphically visualize the information. Digitized video images of each roadway at 50-foot intervals are provided to view the roadway as if driving in a vehicle. Currently only MDOT employees have access to the system.

Development has also begun on additional systems which would access the TMIS database to enhance other operational areas. A permit routing system is currently being designed which will access the TMIS database to assist the Permit Division in routing oversize and overweight vehicles. Web-based routines are also being developed to provide public Internet access to the inventory and map data.

How Is the Bridge Management Information Physically Stored?

The Pontis database resides on a dual-processor Pentium Pro NT 40 server in SQLAnywhere Server 5.0, serving up to 16 concurrent users. District inspectors and bridge division personnel connect to the database via the statewide network. User privileges are established on the database according to the access level needed. Typically, inspectors can add or delete inspection events, add or modify element inspections and add or delete span groups. They cannot add or delete bridges, add or delete elements or modify scenario information.

The TMIS database is Sybase System 11 for Sun Solaris on a Sun Enterprise 5000 running Solaris 2.5.1. The video log digitized images are in a proprietary format running on a Sun Ultra 2 with a Sun StorEdge 3000 providing the disk space (approximately 180 gigabytes currently required). The files are shared to the Windows NT side of the network using SAMBA. Bridge data in TMIS is read only for all users, with the exception of the previously mentioned structure incident function.

The GIS development and maintenance environment is totally within the Windows NT 4.0 operating system. The GIS basemap is developed and maintained using Intergraph MGE/MGSM Version 7 products. Intergraph's Geomedia is used as the GIS querying and mapping tool from within TMIS. The base map data is stored on a dual-processor Pentium Pro NT 40 server.

Minimum practical client configuration is a Pentium Pro computer running Windows NT 4.0 with 64 megabytes of RAM.

How Does the Information Flow from the BMS to Other Systems?

Because the Pontis database is maintained separately from the TMIS database, a method of sharing data had to be devised. A batch process was developed which contains mapping that links Pontis attributes to the corresponding TMIS attribute. This process runs nightly and updates the TMIS database with the current Pontis data. InfoMaker reports were developed which review the results of the upload process and provide information on any errors encountered during the process.

Pre-CADD era design drawings are currently being scanned and, along with current CADD drawings, will be linked to the bridges so that TMIS users can access them from within the software. Likewise photographs, both scanned and digital format, will be accessible from within TMIS. Any TMIS user, with the proper privileges, can store multimedia documents on the server and link them to the bridge within TMIS.

Another batch process is available which checks each bridge's location on the highway network, then creates a file containing the traffic and roadway characteristics needed by Pontis, such as AADT, future AADT, percent trucks, functional class, defense highway indicator, and NHS indicator. This data can then be easily imported into Pontis using simple SQL. Again, the systems were created to be stand-alone to preserve integrity if one should be modified.

How Were the Decisions Made on What to Share or Not Share?

When TMIS was initially conceived, MDOT had only recently acquired the Pontis software. No element-level data had been collected and most inspection/inventory information resided in paper form only. Because of our unfamiliarity with the Pontis programming and optimization modules and a lack of data to properly feed these models, the decision was made to omit this data from TMIS. Additionally, there were rumors that the methodology and database structure within Pontis that supported these functions would likely change in the near future which would cause additional problems. When we have acquired sufficient data to properly use this functionality and our level of confidence with it has improved, we will revisit the need to incorporate these data into TMIS. In the interim, bridge division personnel have access to Pontis' optimization functionality. Provision has been made for mapping Pontis programming and optimization results from within TMIS by simply importing a list of structure keys generated by Pontis. All other bridge inventory and inspection information is shared with the TMIS database.

How Does Embedding a Component in a Larger Database System Constrain the Overall System?

Any system dependent on external programs has the potential to be crippled by version modifications made in the external programs. External programs which are outside the management and control of the agency (such as Pontis) pose an even higher risk since the agency has little input in version modifications. Additionally, variations in supported systems and formats between the components can add further restrictions. For this reason, as well as our relative unfamiliarity with Pontis at the time, MDOT chose to keep it separate from our TMIS system. By doing this, we were able to restructure data distribution within the TMIS database to better fit TMIS. The batch process that maps TMIS fields to the proper Pontis fields effectively provides TMIS with current bridge data and performs additional validation not available through Pontis to ensure data integrity required by TMIS and its GIS mapping systems. This methodology also allows us to use the agency standard Sybase database for TMIS, which is not currently supported by Pontis.

What Have Been the Challenges and the Lessons Learned Setting up Your System?

The single most difficult and time-consuming part in development of TMIS was the establishment of an agencywide common linear referencing system and the subsequent conversion of data to conform to that system. Prior to TMIS, various divisions within MDOT had developed their own methods of data location along the highway network. For example, the bridge data were located by the accumulated mileage along the route from its beginning within the state, basically a route/milepost system. However, pavement data were referenced by route mileage, which started at zero at each intersected county line, a county/route/milepost system. Further issues were encountered with the manner in which the distances were actually measured. Some divisions carried mileage across non-maintained sections while others omitted the mileage of the non-maintained section. Similar issues arose with highway names along concurrent sections. Once a linear referencing system was established, everyone had to convert their data to match. Agreement on a common system and adjusting that data to match that system doesn't signify an end to the issue. It is imperative that everyone involved be committed to the maintenance of that data. Procedures must also be in place to notify subsystem administrators of base map modifications so necessary data adjustment can be accomplished. If one data collector/maintainer fails to keep their portion current, the entire system becomes suspect and a slow but inevitable drift back toward separate data begins.

Another challenge is software maintenance/enhancement after the consultant has completed his portion of the contract. State agencies historically have had difficulty in attracting and keeping personnel with the necessary software development and programming skills to manage a complex system. It is sometimes not feasible to depend on a contractor for support and an agency may find themselves with a system they can't support. High-level administrative support for the system is critical to assure the commitment exists to secure qualified personnel and provide necessary training.

The most important part of the system development is the establishment of a common linear referencing system and a stable, well designed database. Once this has been accomplished, future development can access these foundation-level components without significant reengineering.

MICHIGAN

Who Are the Suppliers of the Information That Is Saved in the Bridge Management Database?

The Michigan bridge inventory databases contain the data necessary to effectively manage the state's trunkline bridges. The information in the database comes from a variety of sources depending on the jurisdiction of the structure. For state-owned bridges, licensed engineers provide element condition data, work recommendations, and other inventory data required by the National Bridge Inspection Standards (NBIS). Dimensional data, project data, and load rating information are collected and maintained by central office staff. Traffic data are maintained by MDOT's Bureau of State Transportation Planning and these data are periodically used to update the bridge management database by a combination of file imports and manual entry. State bridge crew recommendations are made by the inspector but the status of these recommendations is not tracked. Major rehabilitation and replacements are done by contract; the statuses of these projects are maintained by the project managers separately from the bridge inventory database. Michigan does not yet provide for electronic access to as-built plans. However, it is planned that this will be implemented in the future.

For structures owned by local agencies, all data come from the owning agency in paper form which are then processed and batch loaded into the database.

Who Are the Clients for This Information and How Is It Used?

The bridge inventory data are presented and used in several reports. The bridge inspection report is used for a quick overview of the condition and needs for a particular structure. Many summary reports are generated for the use of executives, planners, and region engineers for their use in planning the bridge rehabilitation program, determining funding eligibility, and assessing the needs of the bridge network relative to other transportation needs. More detailed condition data are used by project managers to verify and finalize the scope of work for bridge rehabilitation projects. In addition, bridge condition data are exported as a smaller database for use in generating points for the Critical Bridge Program whereby local agencies compete for a share of the HBRRP funding.

The bridge data are available online for use by designers, planners, executives, and others. The access and use of these data are controlled and only those authorized to alter the data may do so.

How Does the Bridge Management Database Fit into the Larger Transportation Management Database Schema?

In Michigan the majority of the bridge data (NBIS data plus some state-specific data) exists in several tables as part of the Transportation Management System (TMS) Database. The TMS is a state-owned software that is used to retrieve and display information from all six management systems (Bridge, Pavement, Congestion, Safety, Public Transit, and Intermodal). Pontis data are currently stored in a separate database. In the future the Pontis database will be the sole bridge data repository and TMS bridge data tables will be dropped. TMS users will then view bridge data stored in the Pontis database.

The Pontis database will continue to be separate from the TMS database. This allows for changes to either the Pontis or TMS database structures to occur with minimal impact on the other.

How Is the Bridge Management Information Physically Stored?

The databases are currently stored in several places. The bridge management database (non-Pontis data) is stored as part of the TMS Oracle 7.3 database on a SUN server operating in the UNIX environment. Pontis data are stored in a separate Oracle 7.3 database. For Pontis data loading and testing, there is also a Sybase SQLAnywhere instance of the Pontis database residing on a single PC in the Windows NT 4.0 environment. Some ancillary data such as project history are not yet incorporated in either the TMS or in Pontis and are stored as FoxPro databases on a single PC; these will later be incorporated into the Pontis database.

Design drawings (as-builts) will be scanned but the details regarding the storage and access to this information have not yet been determined.

How Does the Information Flow from the BMS to Other Systems?

Other systems that require bridge data may read these data either in those bridge tables that currently exist within the TMS or by querying against the Pontis database. Typically other users' bridge data needs are confined to basic location and condition information which are easily obtained from the bridge tables. The TMS security allows all users of all systems to see the data pertaining to any other system with the exception of legally sensitive material such as accident reports. Security tokens with appropriate privileges are assigned by one person in each of the six management systems and all users must log onto Oracle to access the data.

The flow of information from other systems to the BMS for such items as traffic counts and functional class has not yet been automated. This will be achieved after each structure is located on the linear referencing system.

How Were the Decisions Made on What to Share or Not Share?

MDOT decided to share data whenever possible and have those data items used by several systems updated by the user that "owns" the data. This decision was made to eliminate the situation where several systems may use the same data item (such as ADT for a given location) but the systems differ in what the numerical value for the item is. Each data item is assigned an owner who has control over the updating of the item. Therefore, all users and systems use the same values for all data.

How Does Embedding a Component in a Larger Database System Constrain the Overall System?

Having a combined Transportation Management System has imposed some limitations on the system as a whole. The larger system is updated less frequently than the individual components would be. This is due to a large degree to the fact that not all users are on the MDOT network and therefore have to get their updates via CDs. The logistics of preparing CDs for Public Transit agencies has caused the updating frequency to be much less often than would otherwise be the case. Updates to any component have to be checked to ensure that the overall system is not compromised. Some system functionality is common to several individual components so at times it is not possible to customize a particular system for its own needs if doing so would adversely affect another system.

Version modification has to be continually watched. Pontis versions are released roughly annually, and TMS updates approximately every quarter. Each of these is from time to time upgraded for the version of PowerBuilder. The Pontis installation wizard expects a certain version of Sybase software and does not work on computers with a more advanced Sybase package.

Data security is an issue. There are a multitude of groups with access to the user tables with varying degrees of security for various systems. The maintenance of these user security tokens has been cumbersome. The English vs. metric issue has also caused some problems. The rest of the TMS is in English units while the bridge data are entirely metric. This complicates the ties to the linear referencing system. Having a common database has hampered the ability to revise and expand the bridge portion of the TMS database. A major factor in dropping the bridge tables in the TMS was the inability to alter the tables as new data needs were identified.

What Have Been the Challenges and the Lessons Learned Setting Up Your System?

The greatest challenges have been in processing data inputs from a wide variety of sources and maintaining data integrity. The bridge data come in via several sources, each of which poses its own problems. Local agencies use paper forms nearly exclusively—these forms must be keypunched and put into a flat file, loaded into a test database, validated, and promoted to production status. Each step in the process is a potential source of error. The forms may be filled in incorrectly, errors can occur in keypunching, and the validation routines may be incomplete and not catch a particular error. The procedures for dealing with paper forms evolved through trial and error since not all the possible errors could have been foreseen.

State bridge inspectors used a field application for collecting NBIS condition data, and paper forms for Pontis inspections. The consultant that developed the TMS also made a Field Inspection Application (FIA) that was to collect all the inspection data. It worked well for the NBIS data, but failed to function for Pontis data collection. By the time the fatal flaws were discovered, the contract was over and there was no way to fix the application. Pontis inspection paper forms have proven extremely difficult to process. Common problems included multiple submittals of the same data, entering non-existing elements or condition state, faulty conversions to metric units, and arithmetic errors in computing quantities. The electronic data that are used for NBIS type data has worked well.

Maintaining data integrity has been and continues to be a challenge. Several of the bridge data items in the TMS exist in several different tables. Some of these items get updated and some do not depend on which method (flat file inputs, use of the application, field application) is used for the update process. Attempts were made to develop scripts that would synchronize the data in the various tables. These scripts were run at timed intervals and became known as chron jobs. The chron jobs became very large and complex and were not documented. Some of the chron jobs may have been in conflict with each other so that if one chron job fixed data, another chron job corrupted it. The chron job problem was unique to the bridge tables and contributed heavily to the decision to drop the bridge tables from the TMS and use Pontis as the main repository.

The linear referencing system has been and continues to be a challenge. Planners have found their access to bridge information to be of great value but relating bridge locations to intersections and roadways requires manual effort. The solution is still being worked out—most likely the intersections of roadways will have point IDs associated with them. Each point ID will have one to many physical road (PR) numbers and milepoints associated with it. The point ID will stay the same although the milepoints may change due to realignments and improvements to the road. Point IDs associated with structures will have the structure number and over or under status as attributes. Given a roadway, it will then be possible to determine the point IDs on the roadway within the section of interest, and then find the structures on or under that roadway.

One thing we have learned from the process is that any system or database must allow for expansion. It is impossible to anticipate every single data item that is going to be used for all business processes. Sharing a database and application with other management systems hampers this ability.

Another important lesson is that all systems must be maintained. After the TMS was completed, MDOT chose to do the maintenance in-house. Training the staff in PowerBuilder and learning how the system was designed took a lot of time. During the learning curve, updates and fixes were not possible.

The most important component of a bridge management system is the database. It is imperative that the database is set up by someone intimately familiar with the business process. All updating procedures must be accounted for in the design and there can be no redundancies that introduce the possibility of data losing synchronization.

CONCLUSION

These three states have taken rather different approaches to the integration of their bridge management data into the larger system. California has established a single large database that includes the tables of the Pontis database as well as additional tables of bridge management data and other transportation data. The single database is accessed by multiple applications. Mississippi and Michigan have maintained the Pontis database separately from the other transportation systems and rely on automatic processes to transfer data regularly. For bridge inspection data collection, California relies on its own software system, while Mississippi uses the Pontis interface connecting to the database over their network. Michigan is moving towards a system that will use Pontis Lite on laptop computers in the field and will upload data files from the field via a file import capability of the Pontis software. It is clear that the problems of maintaining compatibility with legacy systems, meeting State specific needs, continuing operations during the implementation of new systems, and providing for future growth require significant development efforts led by the States themselves, and that the solutions reached will be unique to each State that undertakes the effort. We hope to encourage communication and collaboration among States that are establishing or enhancing their transportation management systems.