FINAL REPORT

EVALUATION OF BRIDGE INSPECTION AND ASSESSMENT IN ILLINOIS

Project IVD-H1, FY 00/01

Report No. ITRC FR 00/01-3

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16. Abstract

Maintaining, repairing and rehabilitating Illinois' more than 8,000 bridges in a cost effective manner is critically dependent on reliable inspection and condition assessment data. In the past few years advances in non-destructive testing and inspection data acquisition in the field promise to improve the process considerably. This project explored these advances through a literature review, interviews, surveys, field observations and field-testing. Following extensive interviews and field visits with bridge inspectors and bridge maintenance engineers in Illinois, a survey was distributed to other state Departments of Transportation. The survey identified states using new technologies for data acquisition and visits were arranged to Maryland, Montana, New York and Pennsylvania. Based on the field input and observations in the field, the concept of field data entry and upgraded data acquisition equipment looks the most promising for Illinois. A prototype data acquisition was developed to mimic the current process. Limited field testing met with positive responses. In addition to obtaining new updated equipment, software and training will also be required. The inspection support systems explored in this project are just the preliminary steps in the process of electronically collecting and recording information for IDOT bridge inspections. The procedure can be further developed and simplified in the future as the technology advances. Specific issues include report generation, pen-based application, voice recognition and the development of a web application.

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Evaluation of Bridge Inspection and Assessment in Illinois

Final Report

December 2003

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- Sarah M. Wilson

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This project relied on the willingness of IDOT bridge maintenance engineers and the bridge inspectors to share their knowledge of bridge inspection, answer our seemingly never ending questions, show us what they look for on bridges, and most importantly, demonstrate their commitment to maintain Illinois' bridges in their best possible condition. Their open-ness to new ideas and willingness to work under adverse conditions are commendable.

Likewise, our contact points in other state DOTs, and the bridge inspectors and engineers who were willing to fill out surveys, and have lengthy telephone conversations with us are also greatly appreciated. Their insights and willingness to share information were wonderful.

Finally, the teams responsible for bridge management and inspection in Maryland, Montana, New York and Pennsylvania gave freely of their time, demonstrated their infectious enthusiasm for the topic, and provided a wealth of information.

To all participants in this project, a hearty thank you. We could not have completed the project without you.

EXECUTIVE SUMMARY

Maintaining, repairing and rehabilitating Illinois' more than 8,000 bridges in a cost effective manner is critically dependent on reliable inspection and condition assessment data. In the past few years advances in non-destructive testing and inspection data acquisition in the field promise to improve the process considerably. This project explores these advances through a literature review, interviews, surveys, field observation and field-testing. As a final task, the project provides recommendations for Illinois Department of Transportation (IDOT) for the acquisition and use of these technologies.

There is a wide variety of technologies applicable to bridge inspection and management in various stages of development. As the technology is rapidly changing in this area, we must be careful to balance the capabilities with the availability of ongoing support. While several articles and promotional brochures proclaim the benefits of the technology, an historical overview suggests that there are few experiences with stable technology. It is also clear that the adoption of any new technology requires a comprehensive approach including training and planning for future upgrades. The literature also suggests that each application must be tailored to the needs of the particular agency.

In Illinois, the inspection process varies slightly by district. There are also many different databases that include bridge inspection and assessment data. However, the overall inspection and assessment process focuses on producing consistent data in compliance with the National Bridge Inspection Standards (NBIS) and the inspection data input to the PONTIS® bridge management system.

Based on interviews with bridge inspectors and bridge maintenance engineers in Illinois, there are opportunities for change, but there are also clearly some constraints that are recognized in the following guidelines for the bridge inspection process:

- All changes should be in the context of the current organizational structure.
- New technologies should replicate the existing process.
- New technologies should follow a well-defined process that includes hardware, software, training, and ongoing maintenance and system upgrades.

The fifty state departments of transportation in the United States were also surveyed to identify innovative and relevant inspection practices and technologies. Twenty-seven states responded to the survey. Of the responding states, fifteen indicated that they were using innovative technologies. Follow-up phone calls were made to these fifteen states. Based on the review of the literature, surveys, and telephone interviews, four states were identified has using technology of relevance to Illinois:

- Maryland - Maryland is using laptops in the field to enter data. The data entry system is linked to a process for managing photos and integrating the digital photos into the bridge inspection report.
- Montana - Montana is using a web-based system for data entry and data management. This system is similar to the proposed system in Illinois.
- New York -New York has the most advanced integrated system for data entry and management. It is comprehensive and flexible so there are opportunities to include new data from bridge monitoring or non-destructive testing. The process NYSDOT uses for bridge inspection is very similar to IDOT.
- Pennsylvania - Pennsylvania is using handheld devices for data entry and transfer.

Finally, an XML (extensible Markup Language) version of the IDOT bridge inspection forms was developed for use in the field. These forms were developed using a Java Inspection Framework (JIF), which is a tool to support inspection. The end result of this application is an interface for use by bridge inspectors in the field. This interface provides the inspector with access to historical data and past inspections. Most importantly, it provides an electronic record of field notes that is easily transportable and widely accessible. The data entry form was developed with input from the District 1 bridge inspectors.

The literature review, interviews, surveys, field observation, software development and field-testing presented in the previous chapters serve as a foundation for recommendations to Illinois Department of Transportation regarding the processes, systems and hardware that support bridge inspection and assessment.

General observations related to technology

Field personnel are open to new technology and opportunities to improve the bridge inspection process. However, any changes should be in the context of the existing process. That is, they should not change how the inspectors do their job but make their work either easier or provide tools to enhance the quality and consistency of the inspections, and communication of information. Introduction of any new technology should include not just the acquisition of technology but a well-defined plan to address: 1) interfacing the technology with existing systems, 2) maintaining and updating the technology, and 3) providing initial and ongoing training.

Observations related to non-destructive testing technology

With the exception of dye penetrant and mag-particle, non-destructive testing and evaluation is seen with significant distrust and skepticism. This field is rapidly changing and it is appropriate to explore new technologies, recognizing that adoption of such a technology must follow the general recommendations outlined above. This requires developing new training modules, exploring new methods, and exploring the integration of non-destructive testing data into the databases.

Observations related to data acquisition technology

While a clipboard, paper and pen are the tried and true tools for data acquisition, there is a genuine interest among inspectors to try a more sophisticated method for electronic data entry that would support easy "uploading" of data, seamless access to historical data and appropriate for field use. Many states reported positive experiences with the use of laptops and tablet PCs in the field.

System Development and Control

In all the states we visited, the bridge division played a leadership role in defining the system needs, developing and maintaining the systems. The systems were developed to address the needs of the bridge unit and each state worked around issues and problems to obtain a fully functioning system.

In all cases, the bridge unit claimed ownership of bridge data. This is data that they produce or collect and that they use. In every state visited, they were committed to tying this data to the decision making process, although the degree to which this is currently done varied significantly and no state can honestly say that their bridge inspection data was fully supporting the decision making process, although they all indicated that this was a goal.

Prototype Electronic Bridge Inspection Forms

The prototype XML based inspection forms were favorably received by District 1 bridge inspections. Ideally we would have liked to test the field use of the forms using a PDA, a Tablet PC and a laptop computer for data acquisition. However, IDOT contract restrictions precluded the acquisition of the appropriate equipment.

Based on our discussions with the IDOT bridge inspectors and interactions with the bridge inspectors in other states, we believe that the use of the Tablet PC or laptops in the field offer the most flexible, accurate and reproducible approaches to data entry. The inspectors are able to enter the data as soon as they collect it, they have a device that is easily moved between the office and the field, and they have easy access to an array of historical data. Most bridge inspectors will not take the data entry device onto the bridge with them because they like to keep their hands free and they are concerned with dropping the device. Therefore, there is little to be gained from the compactness of the PDA.

Training, System Support and Quality Control

Training and system support are key to ensuring the proper use and functioning of the system. The initial introduction of a new system requires the acquisition and installation of hardware and software, and training. It is important that all three components occur in a coordinated timely manner rather than piecemeal. Consideration must also be given to system upgrading and ongoing training. This includes access to technical support.

Based on discussions with several states, training and system support are believed to be the critical elements of quality control.

Equipment

Properly functioning state of the art equipment is also essential to an efficient, consistent and comprehensive bridge inspection program. All states that we visited provided their bridge inspectors with offices on wheels. These “offices” included paper files, a laptop or other portable computer, digital cameras, scanners, and printers, as well as the typical equipment required of a bridge inspector (dye penetrant, ladders, hammers etc). Computer equipment was state of the art with appropriate peripherals for connecting to the central office, delivering printed versions of reports and photos, integration of sketches and photos into the bridge inspection report and supporting data entry.

Our overall recommendations based on the research conducted for this project fall into four categories. The first are recommendations related to technology and equipment. The second are organizational issues that must be addressed before IDOT proceeds to develop additional inspection support systems. The third is the process for implementing and supporting systems in the field. The final category includes specific research questions that should be explored in the context of an integrated interface for bridge inspection and assessment data.

Future Research

The inspection support systems explored in this project are just the preliminary steps in the process of electronically collecting and recording information for IDOT bridge inspections. The procedure can be further developed and simplified in the future as the technology advances. Specific issues include report generation, pen-based application, voice recognition and the development of a web application.

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1. INTRODUCTION

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This introductory chapter provides some project background, presents an overview of the research tasks, and finally an outline of the report. The research project was partially directed by the Technical Review Panel (TRP) made up of six IDOT employees. Although the membership of the TRP changed during our research, the TRP always consisted of individuals who worked as bridge maintenance engineers or as bridge management decision makers. The TRP met quarterly. The meetings included briefings on research progress through presentations, reports and memoranda. In our interactions with the TRP, it became clear that the emphasis was on electronic devices for recording inspection data, and less emphasis on non-destructive testing. This report reflects this focus.

1.1. Background

The congressionally mandated National Bridge Inspection program requires States to periodically inventory, inspect, and rate all highway bridges on public roads. The National Bridge Inspection Standards (NBIS), implemented in 1971, prescribe minimum requirements for the inspection of highway bridges in the United States (FHWA, 1995). The mandated inspections provide data for monitoring bridge condition and provide an important input into the decision-making process. They also serve as a safety inspection.

At the same time, up-to-date, accurate and informative data representing the current condition of bridges in the system inventory is critical to the effective use of Bridge Management Systems (BMS). This data allows for proper development of maintenance, repair and rehabilitation programs including those addressing preventive care. Bridge management systems are inherently reliant on the bridge assessment program. As shown in Figure 1, inspection programs are comprised of various time sensitive elements requiring significant investment in time and money, in terms of personnel, as well as instrumentation and training programs.

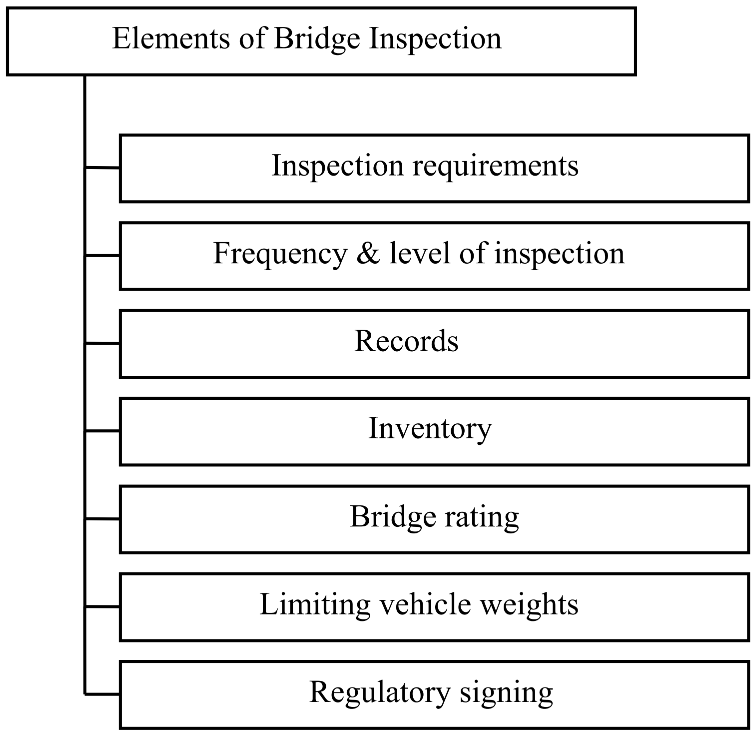


Figure 1. Typical Elements and Processes in a Bridge Inspection Program

Bridge inspection programs have evolved in response to Federal requirements and State needs. Unfortunately, limited budgets of the state Departments of Transportation (DOTs) do not encourage innovation or provide for radical changes in process. When fulfilling the federal requirements is the main concern, there tends to be more “tunnel vision” and an opposition to new methods among the staff. Yet, the information technology revolution has been making small strides. Several states have implemented sweeping reforms that bring their bridge inspection information systems in line with the rest of the business world.

Inefficient data collection efforts have proven costly over time and have slowed progress towards an effective BMS in most DOTs. New technology for data collection, storage and transfer not only addresses many of the constraints and concerns with the existing processes but provides additional condition data needed to make good decisions regarding the tradeoffs among maintenance, repair and rehabilitation strategies. Automated field data collection systems, including hand-held computers, and real-time access to bridge history by field inspectors comprise some of these new technologies. Also, field inspectors need to use enhanced imaging technologies and wearable computers in order to make unrestricted use of their hands for inspection activities. The quicker transferring and updating of field data will provide the bridge authorities with real-time data for the bridges within the inventory. These technologies will result in effective implementation of the BMS and tremendous cost savings for the DOT associated with a proper running BMS. Of course, cost savings should never come at the expense of data quality.

Records must be explicit, complete, and detailed to the extent that they can be fully and correctly interpreted when a complete report is prepared. Inventory reports normally contain the general structure description, history, plans, and inspection data including any structural analysis, which may reflect and best describe conditions and recommendations regarding the bridge and its location.

Data that is not entered into the BMS will not be effectively used. This for the most part occurs due to the fact that additional time consuming and laborious steps are necessary to transfer handwritten information into the digital format to be uploaded into the BMS. Data must be recorded in a format that is useful to the State DOT's in the evaluation of maintenance and repair needs.

Bridge maintenance costs can be astronomical, not to mention that the life of the bridge can be significantly shortened due to inadequacies in the data to support the decision-making process and delays in acquisition, processing and analysis of inspection data. These inefficiencies render preventive care virtually nonexistent, turning the BMS into an ineffective tool. In the final analysis, a goal of a BMS is to make and support strategic, tactical and operational decisions using reliable data.

It is believed that the current state-of-the art bridge inspection technology has matured to the point where it is possible to develop effective and complementary procedures for inspection, data acquisition, reporting, and archiving. The methodologies should allow for a system that easily updates bridge information pertaining to the physical condition of bridges, and provides access to individual bridge histories.

1.2. Research Tasks

The research tasks and objectives for this project were clearly defined by the Illinois Transportation Research Center (ITRC) request for proposals, as outlined below.

Task 1. Literature Review

Literature on inventory, condition assessment and inspection technologies, as well as data management was reviewed and synthesized to provide an overall picture of the state of the art practices and serve as a foundation for subsequent stages of this work.

The areas of interest of the literature review were:

- Manuals
- Tools and Techniques
- Inspection Data and BMS
- Technologies from Other Areas
- Data Management
- Other sources

Task 2. Questionnaire to IDOT Personnel

Understanding the needs of IDOT personnel was critical to the success of this project. Both field and office personnel have concerns, issues and needs. This task helped us identify these elements. Phone interviews were used to administer the questionnaire initially and some follow up visits to specific districts of interest were made.

Task 3. Questionnaires to State DOT's

This task documents experiences in other states that are not documented in the literature. The state DOT's were sent by email a questionnaire that assessed various aspects of their bridge inspection program such as non-destructive evaluation (NDE) use and data collection methods.

Task 4. Conduct in-depth Interviews with selected states

Four states were visited, and a detailed review and evaluation of their experiences based on the data collected in the preceding tasks was conducted. Also included in this decision were the needs of IDOT, as expressed by the TRP and their desires for data collection systems in the future. In the field, the research team observed and documented various approaches to data collection as explained by system developers, bridge inspectors and decision makers. The observations including the attributes of the systems, strengths and weaknesses were critically evaluated and formed the basis of a recommendation to IDOT regarding the acquisition of equipment and procedures for this use.

Task 5. Field Evaluation

Based on the data collected in the preceding tasks including the needs of IDOT, the research team focused on technologies to support data entry. Since no existing system addressed IDOT's specific situation, the research team developed data entry screens that mimicked IDOT's data entry forms. The forms were field-tested with District 1 personnel. This experience provided several insights that were relevant to our recommendations.

Task 6. Final Report.

This final report documents the research methods and findings. The report is intended not only to serve as a useful document for IDOT but as a resource for both IDOT and other states.

1.3. Overview of the Report

This written report includes seven chapters and ten appendices. The following chapter is a review of the literature. Subsequent chapters document the methodology and procedures used, and report the results of the research. The final three chapters are a discussion of results, conclusions, and recommendations. These parts are composed of the work done from the tasks outlined above. The recommendations focus on strategies for streamlining the data collection and recording process for bridge inspection and assessment in Illinois.

There are also ten appendices. Appendix A is a list of acronyms and abbreviations used throughout the report. Appendix B is a detailed literature review including an annotated bibliography. Appendix C includes cover letters and questions used for soliciting information. Appendix D documents IDOT practices. Appendix E documents practices in other states. Appendix F documents practices in states using handhelds and laptops. Finally Appendices G, H, I, and J provide a detailed overview of the processes used in Maryland, Montana, New York and Pennsylvania respectively.

2. LITERATURE REVIEW

A comprehensive literature review of bridge inspection and assessment procedures covering inventory, condition assessment and inspection technologies, as well as data management, was undertaken to document and comprehend the issues surrounding bridge inspection. The sources were grouped into four categories: 1) Manuals of Inspection, 2) Tools and Techniques, 3) Technologies from Other Areas, and 4) Non-Destructive Testing. After reviewing documents identified as relevant to this study, a summary was written to highlight experiences and approaches useful for evaluating and assessing bridge inspection in Illinois. The following brief synthesis is intended to provide an overview of the state of the art and practice. The current state of the art and practice is the foundation for the data gathering and synthesis tasks of this project. A more thorough literature review may be found in APPENDIX B.

2.1. Manuals

To obtain a sense of the practice of bridge inspection in other states, manuals were collected from five states in addition to Illinois (State of California; State of Florida; State of Illinois; State of New York, 1997; State of North Carolina; State of Texas, 2001). Since the size and scope of these manuals vary, the scope and focus of the manuals are summarized in Table 1. For each state's bridge inspection manuals, the strategies employed by the state were identified and compiled in Table 1. The following observations were made:

1. Data Collection:
   All of the State DOTs perform routine inspection every two years following the FHWA requirement. Although some State DOTs do not collect National Bridge Inventory (NBI) data, all of them collect bridge inventory data and additional information that exceeds that required by NBI. States not collecting NBI data derive the ratings from other information. In all states, the data and information collected is entered into a database that can be updated.

2. Non-Destructive Evaluation (NDE):
   Only the States of New York, Florida and North Carolina have NDE procedures in their inspection manual, but not in detail. Among them, New York has the clearest description

though they only list two types of NDE: Dye-Penetrant Testing and Magnetic Particle Testing. Other State DOTs encourage or allow the use of NDE but no inspection trigger/requirement is documented.

3. BMS:
   Each State DOT enters the collected data and information into databases, but not all of them have the link to bridge management system. Some of the states merely use the database to perform queries and develop rankings in their inventories.

Table 1. Comparison of State Inspection Procedures

State	Routine Inspections							In-Depth Inspections				
	Frequency	NBI	lement Level nspection	NDE	ustomized orms	Links to Bridge Management	Supplemental Requirements	Frequency	Trigger	Requirements	Documentation	Rating
California	Biennial	No	Yes	No [1]	Yes	Yes - PONTIS	Earthquake	5 Years	Yes	Yes	Yes	Yes
Florida	Biennial [3]	Yes	Yes	Yes [2]		Yes - BMIS	Quality control	Not fixed [3]	Yes	Yes [4]	Yes	Yes
Illinois	Biennial	Yes	Yes	No [5]	Yes	Yes - PONTIS (MMIS, ISIS)	No	6 Months [6] 12 Months	Yes	Yes	Yes	Yes 0-9
New York	Biennial	NA	No	Yes	Yes	Yes - NYSDOT BMS [7]	Photos, comments and/or sketches	Annual	Yes	Yes	Yes	Yes 1-9
North Carolina	Biennial	Yes	No	Yes [8]	Yes	Unknown	Underwater	2/4/8 Years	Yes	Yes	Yes	Yes
Texas	Biennial	Yes [9]	Yes	No	Yes	No [10]	Underwater	5 Years	Yes	Yes	Yes	Yes 0-9

Notes on Table 1

1. The Area Bridge Maintenance Engineer is encouraged to employ services to perform appropriate NDT to help locate and identify potential problems. No NDT procedures are mentioned in Caltrans Manual. (State of California)

2. Non-destructive testing (NDT) can be used to augment visual inspection. Generally, NDT is not practical for large-scale use on a bridge unless a defect has first been detected by visual means. NDT can be used to highlight or define the extent of the defect. (State of Florida)

3. The condition of a bridge's components, major features and the bridge posting rating establishes the frequency of inspection. Specifically, a rating of 5 or greater requires inspection every two years, 4 require inspection every year, and 3 or less requires inspection every 6 months.

4. Requirements for in-depth inspections refer to "Inspecting Steel Bridge for Fatigue Damage" by John W. Fisher, Research Project No. 72-3 "Manual for Inspecting Bridges for Fatigue Damage Conditions", by John W. Fisher, Research Project No. 85-02, and "Inspection of Fracture Critical Bridge Members" FHWA-IP-86-26.

5. Although not documented in the Bridge Inspection Manual, Illinois follows similar practices to Florida with respect to NDT.

6. This frequency indicates the number of months between fracture critical inspections of a structure that has been designated as having fracture critical members. In practice these may actually be between 12 and 60 months. The actual frequency depends on the condition of the structure. (State of Illinois)

7. This database identifies all bridges and identifies all pertinent information about the bridges including dimensional and weight limitations and a record of all bridge inspections.

8. Special feature inspections for Ultrasonic and Non Destructive Testing are reported separately with a cover sheet that references this type of inspection. (State of North Carolina)

9. Texas captures additional information exceeding that required by the NBI. The data are also used to update the National Bridge Inventory File (**NBI**) for the FHWA. Once a year the complete Bridge Inventory Files for off- and on-system bridges are converted to the actual **NBI** format and submitted to the FHWA. (State of Texas)

10. As of 2001, TxDOT has no formal Bridge Management System (BMS) in place. Some beta testing of the PONTIS® system, which is sanctioned by AASHTO, has taken place, but full implementation of this system is not imminent'. (State of Texas)

2.2. Tools

To obtain an idea of tools used during bridge inspection and maintenance activities, papers describing devices and equipment to aid and assist the inspector were reviewed. The tools identified in the literature review fall into one of two categories: 1) tools used as data storage devices, and 2) non-destructive evaluation (NDE) devices. Section 2.5 is devoted to NDE. This section explores data entry devices.

Before exploring the technologies, the advantages in using data entry and NDE tools, and the reasons for their use are reviewed. Many papers set forth a goal to discuss the reliability and accuracy of visual inspection and to study the influence of human and environmental factors on inspection reliability. Much of this research was conducted using questionnaires distributed to the different state DOT's (Washer 2001). These researchers found that visual inspection is inherently unreliable as a result of the use of multiple inspectors. However, these problems may be reduced using NDE tools to provide objective measures.

Visual inspection techniques are the primary methods used to evaluate the condition of the majority of the nation's highway bridges. Although all bridge inspectors receive a common NBIS training course, several factors such as environmental conditions, the human physical condition, inspectors' experience and performance can affect the inspection result. The Non-Destructive Evaluation Validation Center (NDEVC) of the Turner Fairbanks Laboratory conducted an investigation on the reliability of visual inspection. According to this investigation, in routine inspections, there are large variations in the element-level inspection results, inspection notes, and photographs taken by different inspectors, especially in condition rating. In the in-depth inspection part, the inspection may not yield any findings beyond those that could be noted during a routine inspection when an in-depth inspection is prescribed. The investigation showed that the inspection results were not consistently accurate and need significant improvement (Phares et al, 2000; Phares et al, 2001).

Data storage devices that can in the field store visual inspection data and provide access to past inspection reports to use as a comparison while rating the current conditions may also improve the reliability of visual inspection (Leung, 1997; Hartle et al, 2001; Elzarka, 1999). The data storage device most widely researched is the personal digital assistant (PDA) but all systems are pen-based.

The basic concept is to digitize the inspection form so that the bridge inspector inspects the bridge; stores data and can call up past inspection forms for comparison (Leung 1997). These papers all point out that this type of device can reduce errors because data can be transferred automatically without the threat of transcription errors. Time savings are another big benefit of this type of system. Notes and sketches have been integrated into the PDA to allow for the same capabilities as a paper based system. Most authors give some background on the training required for pen-based systems but do not present a long-term evaluation of the system and the level of satisfaction with the system from the inspectors. An important point made is that the digital forms should not differ drastically from the paper-based inspection forms in order to gain acceptance from the users (Elzarka 1999).

Other data collection devices that were reviewed in the literature were speech recognition systems. These systems have only been used in the laboratory environment and are somewhat promising because they make hands free inspection possible. The initial research showed a high level of reliability of the speech recognition system that compared with the reliability of the pen-based system. The studies, though promising, cannot be generalized as the number of tests were insufficient to be statistically significant and were not done in a controlled environment (Sunkpho 2000).

The papers reviewed provide a clear view of the state of the art and practice and initiated a discussion among the group members and the TRP as to which path the project would take to address IDOT's needs.

2.3. Inspection Data and BMS

Accurate and informative data representing the real-time condition of the bridges in the system inventory is critical to the effective use of bridge management systems (BMS). New technology for data collection, storage and transfer not only addresses many of the constraints and concerns with the existing processes but provides additional condition data needed to make good decisions regarding the tradeoffs among maintenance, repair and rehabilitation strategies (Hearn, 1998).

Non-destructive evaluation provides additional assessment data not available using visual inspection, and that data is more reliable and less subjective than visual inspection. This technology is employed in conjunction with the three predominant materials used in most bridges: concrete, steel and timber. Hearn (1998) and Hadavi (1998) have developed strategies to integrate non-destructive evaluations (NDE) data into bridge management systems. Researchers have also developed deterioration models for BMS using NDE data.

The integration of NDE methods and BMS provide information on condition to the management systems, and allows the management systems to precisely identify changes in condition of elements. Five condition ratings; 'protected, exposed, vulnerable, attacked and damaged' were introduced (Hearn, 1998) to label the condition of Commonly Recognized (CoRe) elements. Thresholds were defined for the raw NDE data in a standard way to mark barriers to different condition states. Hearn's deterioration model considered transition probability for a condition state that is inversely related to the endurance of the stage of service life and the variability and uncertainty in the meaning of measurement. Hadavi also suggested the use of NDE to quantitatively measure condition (Hadavi, 1998). The justification is that quantitative measures can be compared with a limit state standard that uniquely determines the repair or maintenance strategy (Sanford et al, 1997).

BMS is used to manage and organize bridge inspection reports and keep track of inventory records to facilitate better decisions for both maintenance and rehabilitation. Currently, there are gaps in the data collection efforts, data that is collected but not recorded, and data collection efforts that are duplicated. BMS does not provide any systematic procedures for selecting inspection tools. Hearn's strategy aims to integrate NDE data into or with condition ratings, and demonstrates that it is possible to develop a link between BMS and analysis tools.

2.4. Technologies in Use

The technologies that are in use in various field environments provide insights that help us develop realistic plans for IDOT Bridge Maintenance offices. One field that widely accepted the PDA technology is the medical community. The fact that old records are extremely helpful to the health care provider and to the bridge maintenance crew is one of the many strong similarities between the two fields.

In the ambulatory health care field, Electronic Medical Records (EMR) are accessed using PDAs (Barbash 2001). In the past EMR were limited because they were not portable and user friendly. With the addition of a PDA device, the EMR became a more effective tool. No longer would the doctor have to go to desktops connected to the system and read the file or get a print out of what he thought was important. He or she would have all the information in front of him while interacting with the patient, making the decision process for him or her easier. Likewise, the bridge inspector would benefit from this same level of information on the bridge site. Another benefit that the PDA provides to the health care field is improved information sharing and faster requests for work. After the information is collected, it can, since it is already in a digital format, be transferred to many different destinations without having to enter the data into a particular database. For example, data can be sent to medical records, or to the pharmacist taking care of this patient's needs. In terms of request for work, a doctor can make an appointment for a patient if he or she deemed it necessary for x-rays or other tests. Also in this EMR paper the different needs of small and large clinics are explored. They suggest a degree of freedom for the user.

These ideas can easily apply to IDOT needs. The information collected at the bridge site is needed in more than one database and if this transfer can occur automatically, it can eliminate transcription errors transferring data from paper form to electronic database. It is easy to envision an inspector requesting emergency repairs for a bridge. This request can be e-mailed to the proper officials from a PDA. This application also recognizes that each IDOT district is different and has its own set patterns.

In another paper, the Massachusetts Highway Department (MHD) explored electronic bridge inspection. The paper reported satisfaction with a paperless inspection process. They ambitiously wanted to digitize the old data and make it available to the inspector. Also the plans called for MHD central in Boston to download and store all collected information to be disseminated to the regional districts. The information collected would consist of bridge data, video, photo, and CAD drawings. PDA were again used to collect bridge information but only for the PONTIS® bridge management system (Cambridge Systematics, Inc, 2001) information at this point. Also, past bridge information was made available in the field to the inspectors (Leung 1997).

2.5. Nondestructive Testing (NDT) Techniques

Nondestructive testing (NDT) techniques are those test methods used to examine an object, material or system without impairing its future usefulness. This is in contrast with destructive testing where the item being tested experiences some type of damage that requires repair. It can be easily seen why NDT methods are preferable to destructive methods. They can also be advantageous to the owner of the facility from the point of view of cost (Xanthakos, 1996).

The NDE tools that the research team reviewed (based on the literature review) revealed that many of these devices were developed to help infrastructure assessment. The Federal Highway Administration (FHWA) has supported the development of this technology because of the problem of reliability in visual inspection. These technologies also allow for detecting deterioration in its early stages. These technologies can assist in the management of the bridge system by accurately determining maintenance and repair requirements (Washer 2000).

The NDE tools reviewed are the HERMES Ground-Penetrating Radar System and Laser Bridge-Deflection Measurements. HERMES (High-Speed Electromagnetic Roadway Measurement and Evaluation System), although not developed specifically for bridges, has the potential to evaluate decks and identify flaws not noticeable by visual inspection. Bridge deck deterioration in the form of delaminations and spalling can seriously diminish the deck's structural value and lessen the life span of the deck. Detecting these flaws earlier in the bridge life cycle is advantageous, as repairs can be made before more serious deterioration takes place. HERMES uses ultra-wide-band microwaves for flaw detection. The data collected and received is similar to Ground Penetrating Radar for detecting flaws (Washer 2000).

Laser Bridge-Deflection Measurement measures the actual deflection experienced by a bridge in the field. It uses laser to measure bridge deflection from a distance of 30 meters. A computer monitoring system controls the laser and allows the system to scan a large area of a structure for various measurements. The system has a resolution of around one-millimeter, and no special preparation is necessary. This data collected can later be used to estimate the structural load carrying capacity, thus helping to classify the bridge condition (Washer 2000).

Many other tools are being developed and the bridge maintenance office must stay alert to these developments in order to have the highest quality inspection possible.

2.6. Summary

There is a wide variety of technologies applicable to bridge inspection and management in various stages of development. As the technology is rapidly changing in this area, any evaluation must be careful to balance the capabilities with the availability of ongoing support. While several articles and promotional brochures proclaim the benefits of the technology, an historical overview suggests that there are few experiences with stable technology. It is also clear that the adoption of any new technology requires a comprehensive approach including training and planning for future upgrades. The literature also suggests that each application must be tailored to the needs of the particular agency.

3. METHODOLOGY

The research was organized around four areas:

- Data and information gathering
- Information structuring
- Development of prototype software
- Field tests

The approach used for each of the areas is described below. These areas should not be considered to be discrete and independent. For example, insights gained from the information structuring area informed the data and information gathering efforts.

3.1. Data and Information Gathering

Data and information were gathered from paper and electronic media, questionnaires, interviews, field visits and surveys. Interviews and field visits used a series of structured questions to ensure consistency and completeness. The process occurred in several stages. The target source of data and strategy at each stage were:

- IDOT Personnel – interviews and field visits
- State DOTs – email survey
- Selected state DOTs - follow up telephone calls
- Targeted state DOTs - field visits

Each is described in more detail in the following sections.

IDOT Personnel – interviews and field visits

Understanding the needs of IDOT personnel is critical to the success of this project. Both field and office personnel have concerns, issues and needs. This task identified these elements. One-on-one meetings, field visits and telephone interviews were used to explore the needs of IDOT with respect to bridge inspection and assessment. The questions used for the telephone interviews area included in APPENDIX C. In summary, the report draws on:

- Visits to Districts 1, 2, 3 and 8 including field inspections
- Telephone interviews with all district bridge maintenance engineers.

- Telephone interviews with 15 bridge inspectors
- Participation in inspection of I-55 bridge across Des Plaines River.
- Meetings with Central Office BMS personnel
- Meeting with Bureau of Information Procession personnel
- Reviews of IDOT reports

State DOTs – email survey

To understand what is happening in other states and go beyond what is documented in the literature, the research team developed a survey that was administered by IDOT. The survey was developed with input from the Technical Review Panel. Members of the Technical Review Panel pretested the survey. The survey and cover letter are included in APPENDIX C.

The survey was emailed to the American Association of State Highway and Transportation Official's (AASHTO) Research Advisory Committee (RAC) listserv contact in each state. They were asked to forward the email to those in the state that are responsible for bridge inspection and rating assessments.

The survey focused on the following areas:

- Type of routine inspection
- Who conducts inspections
- Time taken for a typical inspection
- Where the data entry is done
- Time required for data entry
- Number of inspectors and number of bridges
- Size of typical inspection team
- Qualifications of inspectors
- Databases used
- Bridge management system used
- Devices used for data collection
- Non-destructive testing technologies
- Use of bridge monitoring and remote monitoring
- Ongoing research

The survey was designed to be completed in less than 15 minutes. IDOT initially received responses from 26 states and one additional state responded after a reminder had been sent out. Response data for Illinois was also added. Table 2 lists these 28 states.

Table 2. States Responding to the Survey

States Responding		
Alaska	Maryland	Ohio
Arizona	Michigan	Oregon
Arkansas	Mississippi	Pennsylvania
Connecticut	Missouri	Rhode Island
Delaware	Montana	South Carolina
Georgia	Nebraska	Utah
Illinois	Nevada	Virginia
Indiana	New Hampshire	Washington
Iowa	New Mexico	
Kansas	New York	

Follow up telephone calls

Based on the survey results, the research team identified fifteen states that were using "interesting" technology in the field such as laptops and handheld devices. The follow up telephone calls obtained more specific information. No new non-destructive testing technologies or bridge monitoring activities were revealed in the survey.

The questions used for the telephone interviews can also be found in APPENDIX C.

All the telephone interviews addressed the following areas:

- Technology used
- Location of data entry
- Data interface
- Duration of use
- Use of customized software

Targeted state DOTs - field visits

Based on the telephone interviews, four states were identified for field visits. The field visits focused on determining if the technology is appropriate for use in Illinois, and the suitability of the technology for field evaluation in Illinois.

The original proposal identified the following criteria for selecting states:

- Does the state use specific technologies of interest to IDOT?
- Does the state use technology appropriate for export?
- Does the state have experience with specific technologies that may provide insight into acquiring a technology for IDOT?
- Are the procedures used relevant to IDOT?
- Is the environment in which the technology operates and the context in which the agency does business pose any constraints for IDOT?

All states identified had *systems* rather than particular types of technology or hardware that is relevant to Illinois. Visits were scheduled to include interviews with personnel at different levels in the organization, and if possible, field observations. Checklists and structured interviews were used to ensure a comprehensive and consistent approach. A typical itinerary included:

- Meeting with original contact
- Meeting with bridge engineer or assistant
- Meeting with personnel responsible for bridge inspection
- Meeting with personnel responsible for bridge management
- Meeting with bridge inspector
- Field bridge inspection

The questions used for the interviews can also be found in 0.

3.2. Information Structuring

The results of the data and information gathering were organized into summary tables, and charts in the "Results" chapter of the final report. In general the results of surveys are entered into spreadsheets for easy analysis, and categorization. Photographs and schematics are also used to illustrate the concepts and provide a visual image of specific pieces of equipment.

3.3. Development of Prototype Software

Prototype software was developed to demonstrate the utility of field data entry of inspection data. The XML software runs on a laptop computer and can be ported to a tablet PC or PDA. The software was developed to produce an electronic version of the IDOT inspection form from which data can be automatically uploaded into the databases.

3.4. Field Tests

The field tests were designed to test the capabilities of the software, and assess its limitations. The field tests were conducted in two stages. The first stage explored the utility of the software for the field inspectors. The second stage explored its application to multiple bridges following some simple modifications to address concerns identified during the first stage.

3.5. Development of Recommendations

Based on the results obtained from each of the stages findings were synthesized and assembled into recommendations for IDOT.

4. PROJECT RESULTS

This chapter presents the project results. The first section describes IDOT practices. The second section presents the results of the survey of other states with the third section documenting the results of the more intensive review of states using hand held devices and laptops in the field. The fourth section describes the field visits to Maryland, Montana, New York, and Pennsylvania. The final section presents the data entry interface developed for Illinois.

4.1. IDOT Practices

The inspection process varies by district. However, the overall process focuses on producing the same results, specifically National Bridge Inventory (NBI) inspection data and PONTIS® inspection data. The experiences in each district are documented in 0. Table 3 summarizes basic information about each district. The table is not intended for comparisons of the districts but to illustrate the similarities.

The decision-making process relies on a variety of Bridge Management tools and databases that are used at IDOT. Those relevant to this study are summarized in Table 4. The relationships among the various tools are shown in . As the table and figure show, there are many acronyms used for the computer systems and databases. These are defined in Table 4 and APPENDIX A.

In the mid 1990's many of the inspectors participated in a field trial using Newton Apples for data entry. These hand held computers had an early version of hand writing recognition software. Most inspectors found them "clunky" and difficult to use. Software was not properly installed, the hand writing recognition software did not function consistently, uploading of data was problematic and most inspectors felt that there was not adequate support.

The meetings and telephone interviews provided a foundation for some observations and preliminary findings that include:

Table 3. Summary of Inspection Process by District. (July 2003)

District	No. of Bridges	Deck Area (sq ft)	Crew Size	Full Time Inspectors	Part Time Inspectors	File	Clean Form
1	1469	22,247,165	2	23 (3 vacant)	0	Yes	No
2	1000+	7,672,932	2	5 (2 vacant)	2	Yes	Yes
3	875	5,984,029	2	4 (1 vacant)	10	Yes	Yes
4	600	5,460,282	2	3	1	Yes	No
5	875	5,327,749	2	4 (2 vacant)	2	Yes	No
6	970	6,679,801	2	4 (2 vacant)	2	Yes	No
7	734	4,050,026	2	4 (2 vacant)	2	Yes	No
8	900+	8,755,749	2	6 (4 vacant)	6	Yes	No
9	630	3,877,456	2	2	2	Yes	No
Total	~8,000	70,055,189		55 (16 vacant)			

- Districts follow similar practices in terms of bridge inspection process and data entry. Most inspectors work in teams. They review the inspection file before going onto the bridge and then make notes on the bridge. They fill out the form in the truck and do the data entry some time later or pass it on to someone else.
- Quality control is limited to "potential problems." There is significant concern with identifying a bridge component as being in poor condition when it is not justified. Little attention was focused on rating a component or element in better condition than it actually is.

- There is genuine interest in improving the process. All inspectors demonstrated a commitment to their job and were interested in techniques and technologies to improve the process.
- Extremely variable knowledge and practice of NDE. Most of the inspectors and bridge maintenance engineers had an opinion about NDE but it was difficult to determine how well informed they were. Many of the technologies mentioned by the inspectors have changed and evolved over the last decade.
- Limited resources and the need to inspect many bridges impose constraints on the bridge inspection process.
- There are very different relationships with other units in each of the districts. For example, some bridge inspectors are able to easily update inventory data where others go through a complicated process to update information.
- There are many databases and software tools. There is great variability in who has access to data and the familiarity of users with specific software. This raises the potential for redundancy and inconsistencies.
- Many of the data issues are part of a series of larger issues related to ownership of data, lack of communication, lack of co-ordination of training, and other organizational and institutional issues.
- PONTIS® essentially serves as a sophisticated filing system for quantities. Use of that data varies from district to district.
- There is a two-tiered inspection process. Bridges that do not exhibit any obvious problems to the inspector are rated, and recorded. Bridges with problems are carefully scrutinized at multiple levels to ensure safety and an appropriate response.

While there are opportunities for change, there are clearly some constraints and processes that should be followed:

- All changes should be in the context of the current organizational structure.
- New technologies should replicate the existing process.
- New technologies should follow a well-defined process that includes hardware, software, training, and follow up.

One of the useful ideas posed by more than one interviewee was that district bridge engineers should share Structure Information Management System (SIMS) queries. Most of the district bridge maintenance engineers use SIMS to generate program information and to answer questions. They do not use SIMS frequently and most of them have had very limited training. Sharing queries would give the district bridge maintenance engineers access to a library of queries that can be tailored to suit their particular needs.

There were also some surprises identified in the interviews. The surprises were:

- Some districts valued the Newton Apples as a tool for data entry and access
- Some districts would like to have laptops in the field
- Some districts use tape recorders
- Some districts have developed fairly detailed document management systems (For example, they have systems that include digital pictures.)
- Many districts are interested in piloting new technology.

The research team also met with personnel from the Bureau of Information Processing (BIP). BIP personnel were developing a web-based system for data entry. The effort (as of February 2003) was in the very preliminary stages but would address many of the concerns raised in the interviews and field visits. A subsequent reorganization of information processing functions means that the future of this system is uncertain.

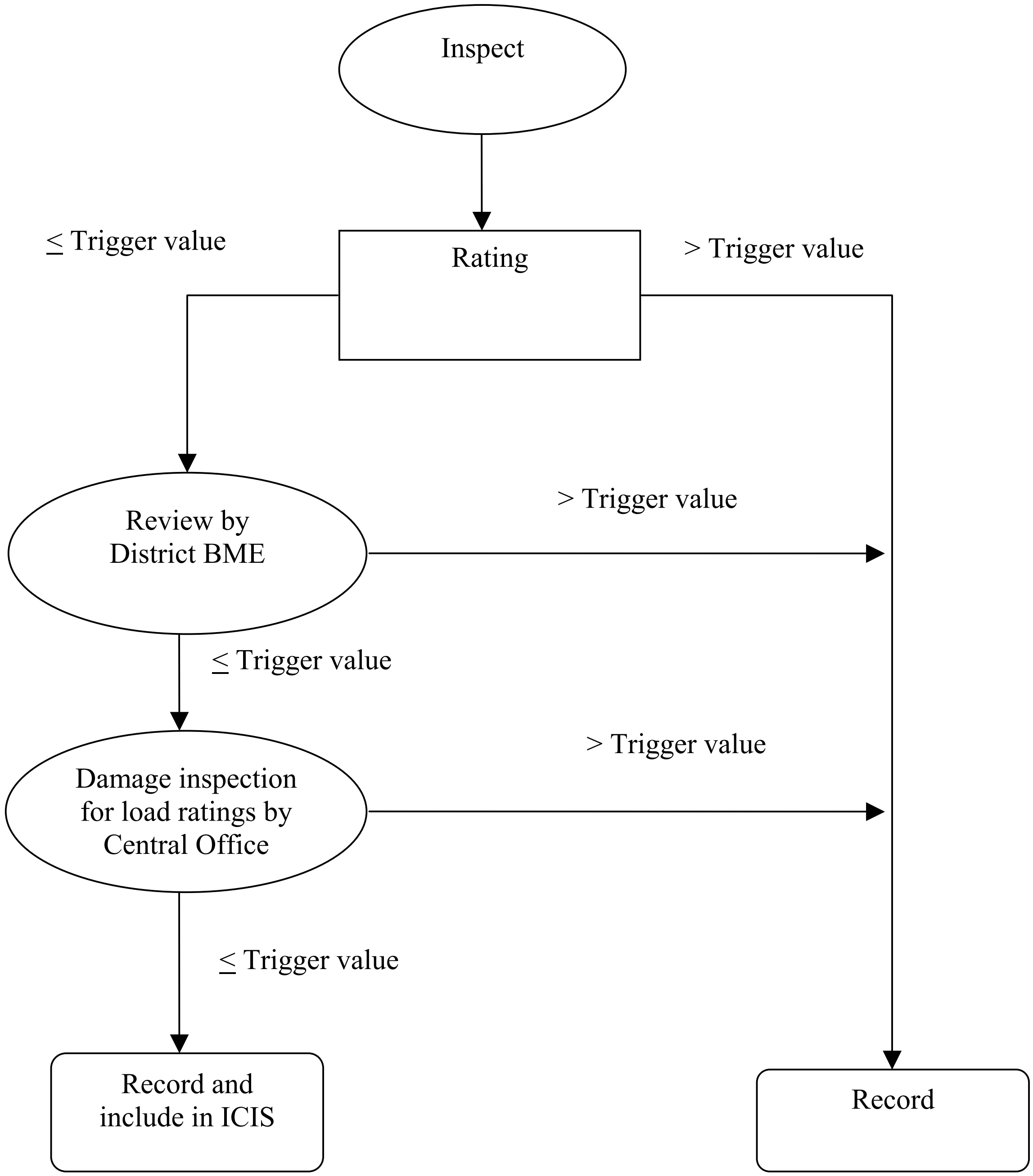


Figure 2. IDOT Inspection Process

Table 4. Bridge Management Tools and Databases.

Name	Ownership/ Access	Language	Bridge Data	Links From…	Links To…
AASHTOWare PONTIS®	Districts, Bureau of Bridges and Structures, and Office of Planning and Programming (OP&P)	Links to Sybase database	Inventory, NBI data, Pontis elements and ratings	ISIS	SIMS
AASHTOWare Virtis/Opis®	Bureau of Bridges and Structures	MS SQL/ACCESS	Bridge Rating and Design data		ISIS (manual)
BAMS – Bridge Analysis and Monitoring System	OP&P	EZTrieve+	Compares structures against set criteria	ISIS	PPS
BARS – Bridge Analysis and Rating System [1]	Bureau of Bridges and Structures	Fortran	Load rating and permitting	-	ISIS (manual)
BPT – Bridge Project Tracking	Bureau of Bridges and Structures	Nomad	Bridge Planning, Design, and Repair Project data	PCS, ISIS	SIMS
BPT – Bridge Project Tracking (New)	Bureau of Bridges and Structures	Microsoft SQL/ACCESS		PPS, ISIS	SIMS
Element Level Inspection Database	Bureau of Bridges and Structures	Microsoft SQL/ACCESS	Element Level Inspection data	PONTIS®	SIMS
IRIS – Illinois Roadway Information System	OP&P	IMS/COBOL	Traffic and highway data	-	ISIS
ISIS – Illinois Structures Information System	OP&P	COBOL	Inventory, NBI data	IRIS and MMI BARS (Manual)	PONTIS etc
MMI – Maintenance Management Information System [2]	Bureau of Operations	COBOL	Bridge inspection data, maintenance data and cost data	ISIS	ISIS
PCS – Pre-Construction	Districts, Bureau of Bridges	Nomad	Improvement projects	PPS	BPT,

Status System	and Structures, and OP&P				SIMS
PPS – Planning and Programming System	OP&P	COBOL MS SQL/ACCESS	Categorization	BAMS	SIMS, BPT, PCS
Repairs	Bureau of Bridges and Structures	Microsoft SQL/ACCESS	Bridge Repair and Maintenance Project data	ISIS	SIMS
SIMS – Structure Information Management System	Bureau of Bridges and Structures, and OP&P	Microsoft SQL/ACCESS	Inventory, NBI data	ISIS, BPT, Repairs, PONTIS®, PPS, PCS	

[1] BARS is “sunsetting,” IDOT is moving to Virtis®

[2] Bridge data being removed from MMI

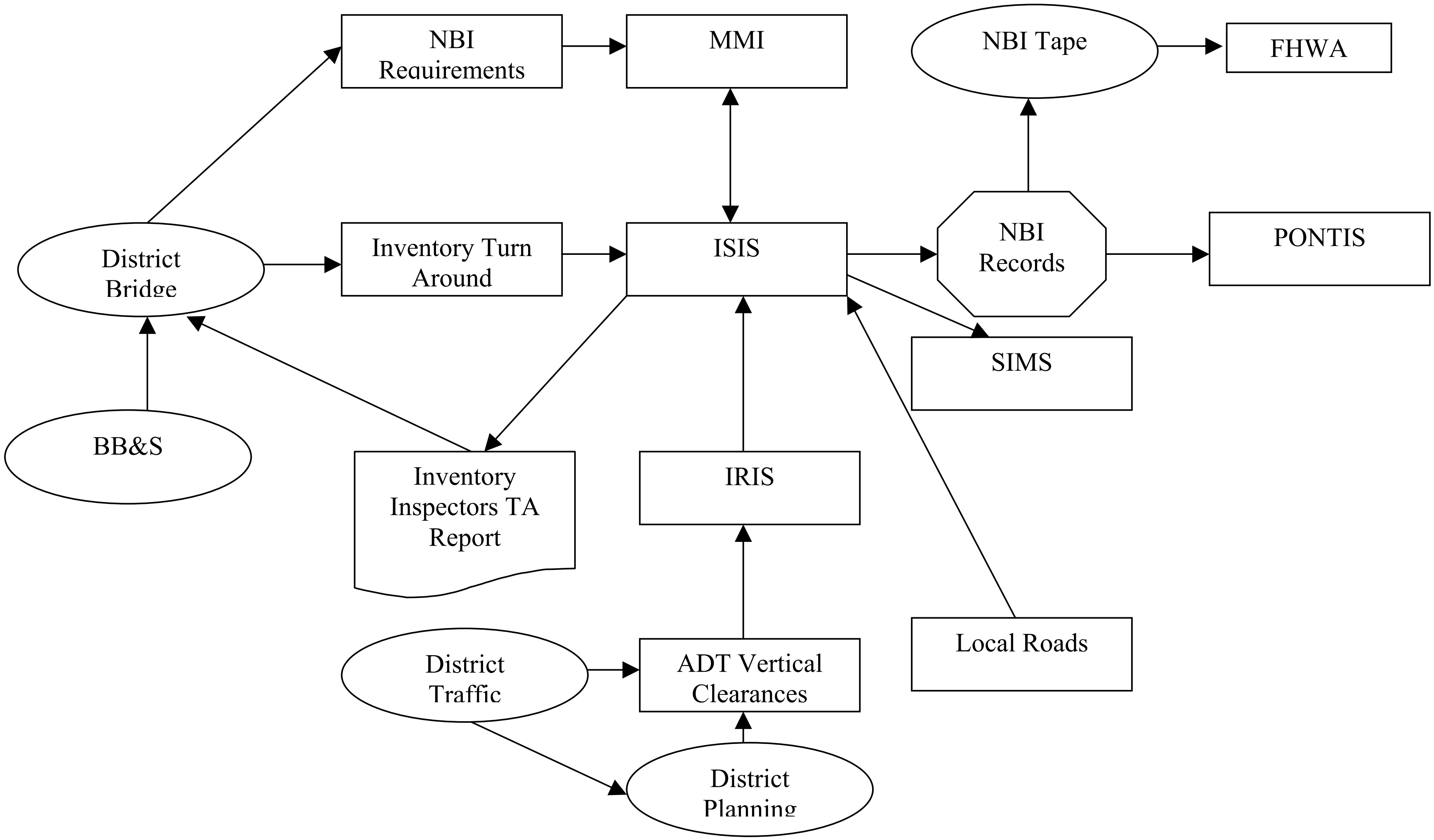


Figure 3. Software and Databases for Bridge Management

4.2. Survey of Practices in Other states

The survey of other states was distributed via email. Twenty-seven states responded to the survey. The results of the survey are documented in a working paper included in 0.

The following observations are made based on the data provided by the states responding to the survey:

- All states but one undertake NBIS inspections. The state that does not complete NBIS inspections converts PONTIS® inspection data to the NBIS format using formulas approved by FHWA.
- All states use DOT employees for routine inspection.
- Many states use some combination of employees and contracts for inspection.
- Inspection of a typical bridge takes 1-4 hours and data entry typically takes less than an hour.
- The typical inspection team consists of two inspectors.
- Almost 70% of responding states use PONTIS®.
- The majority of responding states using PONTIS® use Oracle as their database.
- Almost 60% of responding states regularly use laptops for field data collection.
- Ultrasonics is the most commonly used non-destructive testing technology.
- Over 60% of responding states do some data collection in the field.
- Few states do large scale monitoring or remote monitoring of bridges.
- About 75% of responding states have ongoing research on bridge inspection, data collection or data management.

Overall, the results are not surprising and fairly consistent with the reported national trends.

Table 5 summarizes the responses from each of the states. The last column of the table details the use of innovative technologies (including laptops and hand held devices).

Table 5. State Specific Responses

State	No of Inspectors	No of Bridges	Interesting and Relevant Uses of Innovative Technology
Arizona	4	6,673	Laptops
Arkansas	20	~12,300	Working towards data collection using laptops
Connecticut	20	5,200	Conducting research on bridge monitoring
Delaware	8	1,400+	Laptops
Georgia	26	14,500	Fiber optic sensors/ Laptops
Illinois	55	~8,000	_
Indiana	15	5,300+	Laptops
Iowa	17	4,100	Conducting research on electronic clipboards
Kansas	10	8,500	Electronic Clipboard
Maryland	18	~2,400	Remote monitoring/ Laptops
Michigan	35	~5,000	Remote video cameras/ Laptops
Mississippi	12	5,442	_
Missouri	~7	~6,600	NA
Montana	~30	4,640	Laptops
Nebraska	275	16,000	Develop system combining inspection, GIS and digital photography
Nevada	3	~1,700	Hermes GPR/ Laptops
New Hampshire	6	3,693	Laptops
New Mexico	15	4200	Digital Photography/3 Pt Coordinates & Laptops
New York	160	26,250	Laptops
Ohio	32	15,000	Laptops
Oregon	8	6,550	Laptops (occasional)
Pennsylvania	50	20,000	PDA
Rhode Island	14	750	Tape recorder
South Carolina	25	9,000	Bridge load test program/ Laptops
Utah	6	2,800	Laptops
Virginia	80	18,000	_
Washington	40 (12-15 FTE's)	~3,400	Laptops/ Migrating to wearable technology

4.3. States using Laptops and Hand Held Devices

The research team conducted in-depth telephone interviews with 15 states based on the responses from 27 states to a survey distributed via email. The 15 states were Alaska, Arizona, Arkansas, Delaware, Georgia, Iowa, Kansas, Maryland, Massachusetts, Montana, Nevada, New York, Pennsylvania, Utah, and Washington.

Based on the review of the literature, the surveys and telephone interviews, several states are undertaking efforts to address the issues of concern to Illinois. These are:

- Maryland - Maryland is using laptops in the field to enter data. The data entry system is linked to a process for managing photos and integrating the digital photos into the bridge inspection report.
- Montana - Montana is using a web-based system for data entry and data management. This system is similar to the proposed system in Illinois.
- New York -New York has the most advanced integrated system for data entry and management. It is comprehensive and flexible so there are opportunities to include new data from bridge monitoring or non-destructive testing. The process NYSDOT uses for bridge inspection is very similar to IDOT.
- Pennsylvania - Pennsylvania is using handheld devices for data entry and transfer.

4.4. Field Visits to Other State DOTs

The research team visited Maryland, Montana, New York and Pennsylvania. In all states except New York, we met with both central office staff and field inspectors. In Maryland and Montana, we actually completed a bridge inspection with an inspector. The size of the states visited and the number of bridges they are responsible for vary significantly. Table 6 summarizes the basic characteristics of each of the states and includes similar data for Illinois.

All four states visited have customized software for field data entry that interfaces with the bridge management systems or databases that are used to support decision-making. New York, Maryland and Pennsylvania all perform data entry in the field (laptops in New York and Maryland and a pen-based system in Pennsylvania) and upload the data to a centralized computer system on a regular basis. Montana inspectors enter their data in the office. In all four states, the bridge section controls the process and has demonstrated strong leadership in establishing a system that meets the needs of the organization. The following sections detail the experiences in each of the states.

Table 6. Characteristics of States Visited

State	Number of Bridges	Size (sq miles)	Popu-lation (2000)	Number of Inspectors	Features	Bridge Management System
Illinois	8,000	55,584	12,419,293	55 full-time	Not applicable	PONTIS®
Maryland	2,400	9,774	5,296,486	18 full-time	Digital photos	In house, formerly PONTIS®
Montana	4,640	145,552	902,195	2 full-time ~28 part-time	Web-based data entry	PONTIS®
New York	26, 250	47,214	18,976,457	160 full-time	Integrated system	In house
Pennsylvania	20,000	44,817	12,281,054	50 full-time	Pen-based system	In house

A Digital Photo Library: Maryland

Maryland collects both PONTIS® and NBIS data, although, like Illinois, they do not regularly use the PONTIS® data is any systematic or formalized manner to support long-term decision-making at the district level. Each bridge inspection crew has an assigned territory and they enter the data in the field on a laptop. The laptop includes all historical inspection data back to 1994/1995 including forms, elevations, and soundings. Any changes in the ratings require a narrative documenting the change. Issues and concerns are reported via a flag known as a "screamer." For the past two years, the files have included digital photos. These photos have a logical naming scheme to ensure easy access.

The bridge management section maintains a number of databases to facilitate data entry and data access. The applications have been developed to address a specific need and do not represent an integrated system. However, because of the size and scale of the operation, the process is relatively seamless to the inspectors and engineers.

There are two key features of the Maryland system. First, the system involves a well-defined process for managing photos that is separate from data entry. Second, Maryland's electronic document management system allows access to plans and drawing that can then be emailed to inspectors for use in the field. More details of the process, and photo naming conventions are included in APPENDIX G.

A Web-based Interface: Montana

Montana DOT (MDOT) has played a leadership role in developing a web-based interface for PONTIS®. The html/xml interface is available to the general public as well as inspectors. Inspectors have password access to specific functions and fields. Documentation, manuals and help are also available online. Inspectors and engineers also use the system for queries and access to the database. The system can be accessed at: http://webdb2.mdt.state.mt.us/pls/bms_pub/PONTIS40_site.htm. A more complete description of the system can be found in APPENDIX H.

Although the inspectors have laptops, they tend to take notes in the field and enter data in the office. MDOT has found that because there is no software to distribute, the application is very stable and inspectors appreciate the elimination of much of the mindless work of data entry.

The key features are:

- Web-based system with three levels of users (general public, bridge inspectors, system administrator)
- Interface links directly to PONTIS®
- User friendly interface including search capabilities

An Integrated Data Collection and Access System: New York

New York State Department of Transportation (NYSDOT) has been a leader in bridge management systems. NYSDOT developed an inspection process and database before it was federally mandated. They have over 90 fields that include span-by-span ratings. Inspectors do all data entry in the field on laptops. The data inspection system was developed in-house to interface with the bridge management system. More details are provided in 0.

The data entry system has two key components:

- BIPPI – **B**ridge **I**nspection **P**en **I**nterface. While the system was never actually used with a pen interface, the inspectors use this interface in the field to enter their data into a laptop computer. The inspectors have all the recent inspections preloaded via DVD or CD. The BIPPI interface ensures that the inspectors have access to all the correct forms and can integrate photos, sketches and notes into the system. The interface is shown in Figure 4.
- WINBOLTS – Windows Version of the Bridge Online Transaction System. This system links inspection information with inventory.

In addition, software for uploading data is provided to the inspectors. Both systems were developed in-house. The most important features of this system are the integration of photos and sketches, and final product of the system. This final product is a pdf file that is the actual inspection record.

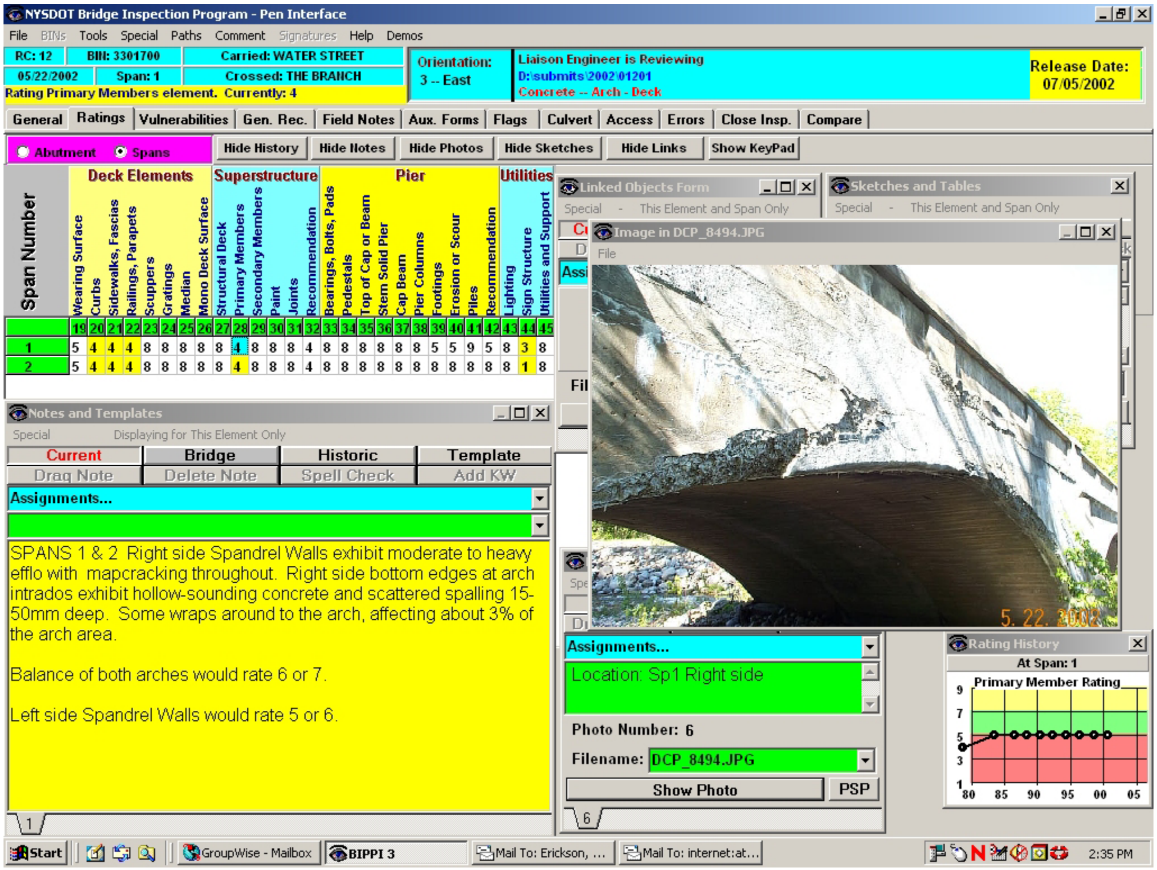


Figure 4. BIPPI Interface

An Application of Handhelds in the Field: Pennsylvania

Like New York, Pennsylvania has been a leader in bridge management. The electronic data entry system known as E-Forms is probably the most sophisticated field data entry system. The development of E-Forms began about 6 years ago and was developed in-house using a consultant (Hartle et al, 2001). The system was designed around the idea that data should only be recorded once, the actual bridge management system cannot be changed and the paper copy is the legal record. This system is fully integrated and closely links the inspection process to training and quality control. While the system is intended to be used on the bridge, most inspectors complete the data entry in the van as shown in Figure 37.

In addition to the NBI data, Pennsylvania's BMS includes an additional 100 fields. The inspectors provide text to support their ratings. This is a very labor-intensive process. With

20,000 bridges inspected every year, the opportunity to save 30 minutes per bridge using the Electronic Data Collectors (EDCs) constitutes a substantial savings.

A more detailed description is provided in 0. The key elements of the system are the impact on inspector efficiency and the fact that data are entered only once. Maine DOT recently conducted an evaluation of E-Forms and found that the software had many of the capabilities that Maine was looking as an interface for data collection (Gesualdo and Harris, 2002).

Figure 5. Use of Pennsylvania's EDCs

4.5. A Data Entry Interface for Illinois

An XML version of the standard IDOT inspection form BBS-BIR-1 was also developed (Bao, 2003). XML – eXtensible Markup Language format means that the system can run on many different devices and data is easily transferable between applications. The XML application captures ratings for each of the elements and allows the inspector to record the narrative that supports their specific rating.

Figure 6, Figure 7, and Figure 8 show the various screens in which inspection tasks are displayed in the IDOT NBIS inspection support system and how these tasks are conducted. Figure 6 shows how the bridge general information and the previous inspection record is called and displayed. Inspectors may revise the bridge information and change the appraisal rates. Figure 7 shows how the support system displays photos and sketches as a reference for bridge inspectors. Figure 8 presents the screen showing the tasks listed under the superstructure inspection element and the appearance and structure of the inspection interface. Using this interface, bridge inspectors fill in the ratings for each element in the appraisal box and write down the defects and comments in the comments area as notes when necessary. In the example of Figure 8 the element “bearing devices” is rated as “3” and noted as “poor condition”.

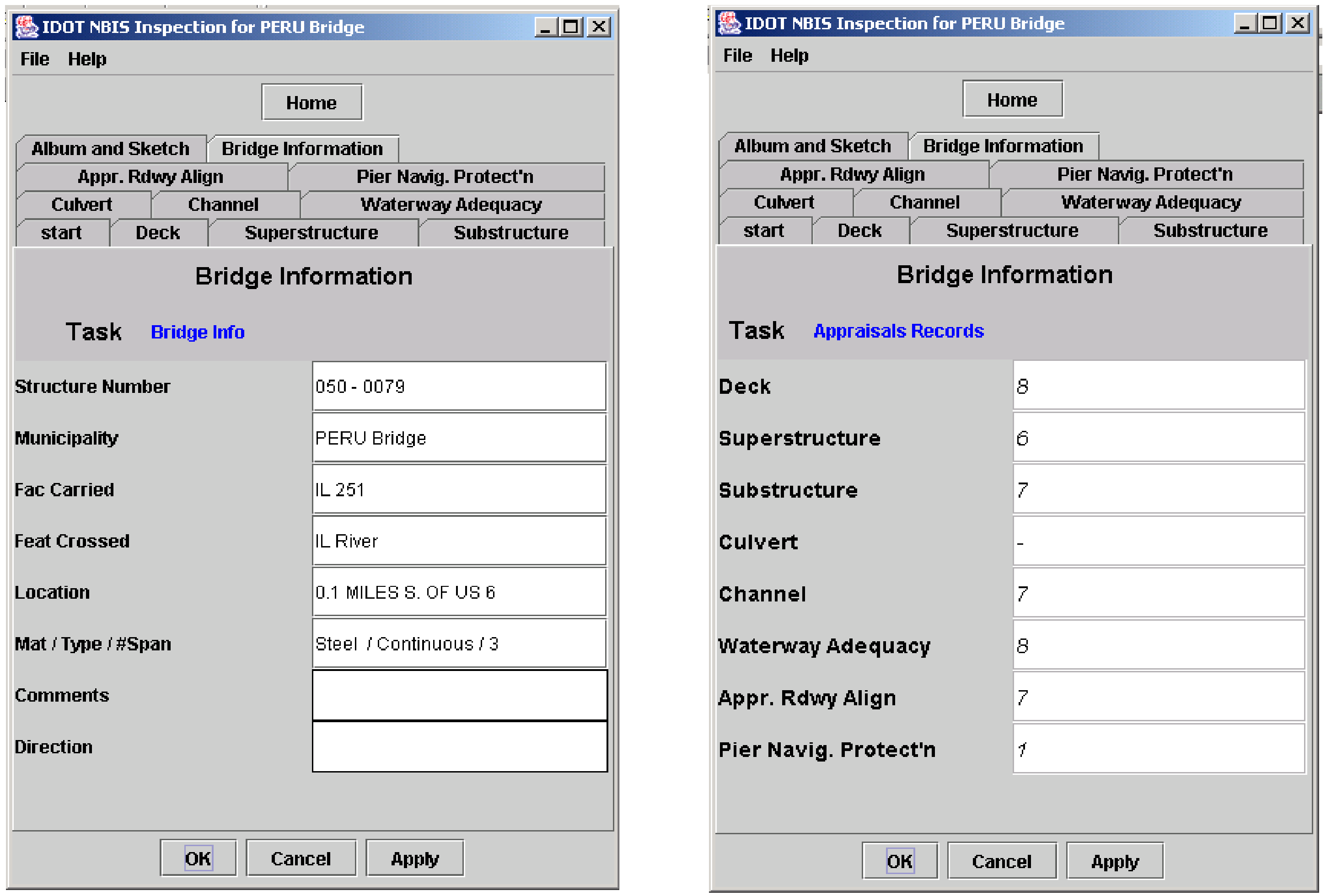


Figure 6. Screens of Bridge Information and Previous Rating Records Windows

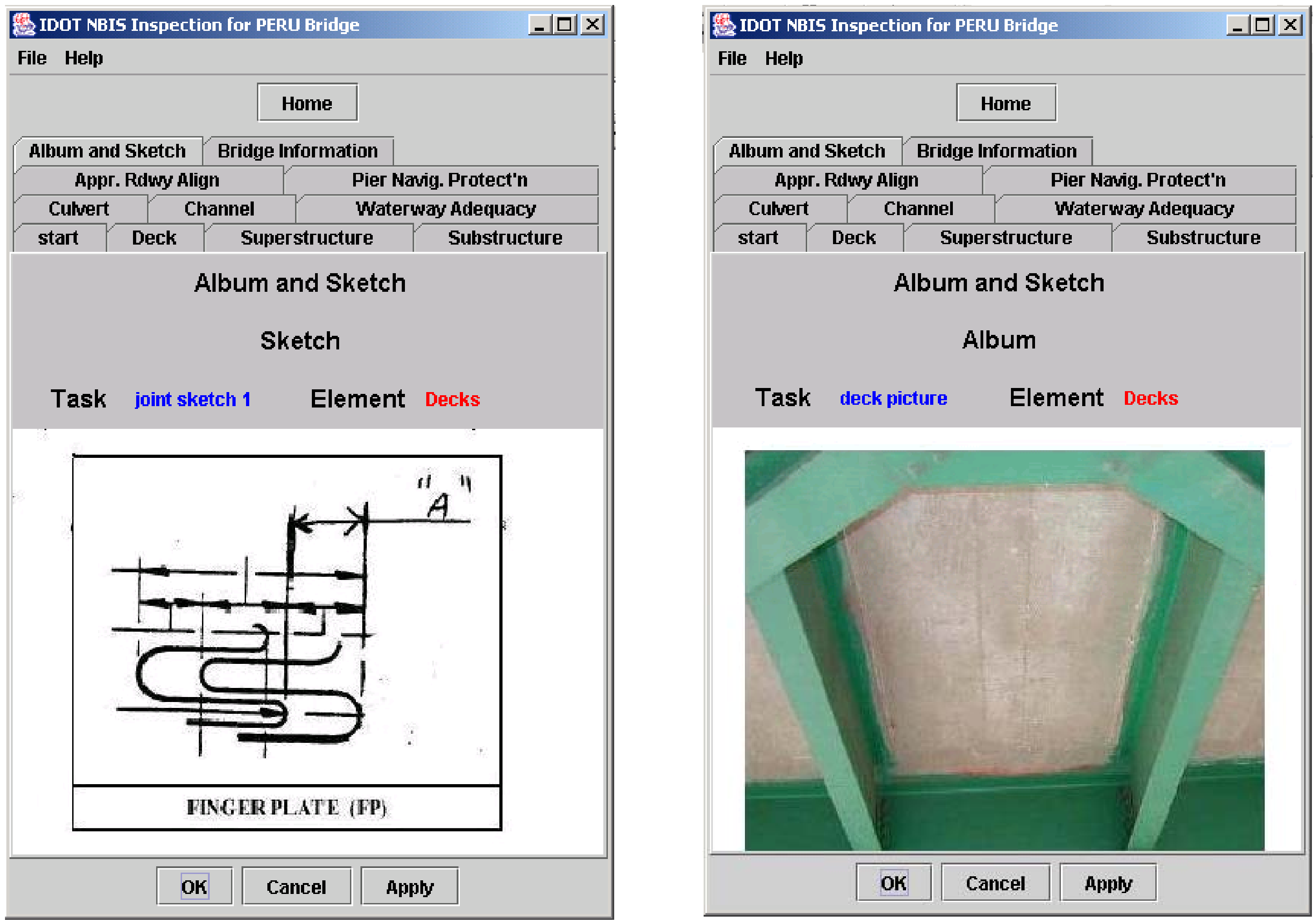
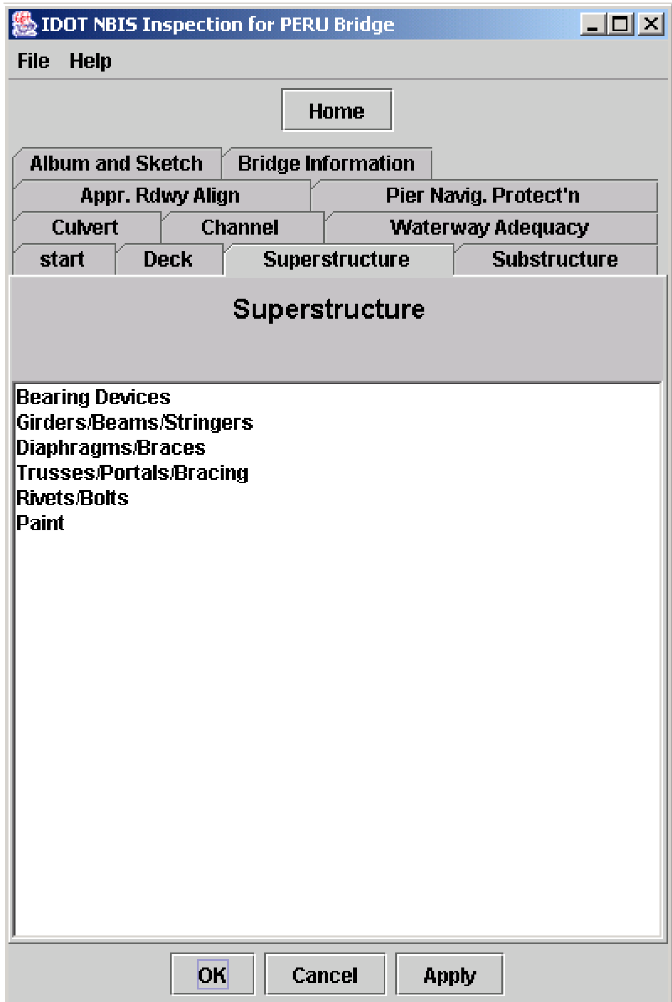


Figure 7. Screens for Sketch and Photo Display



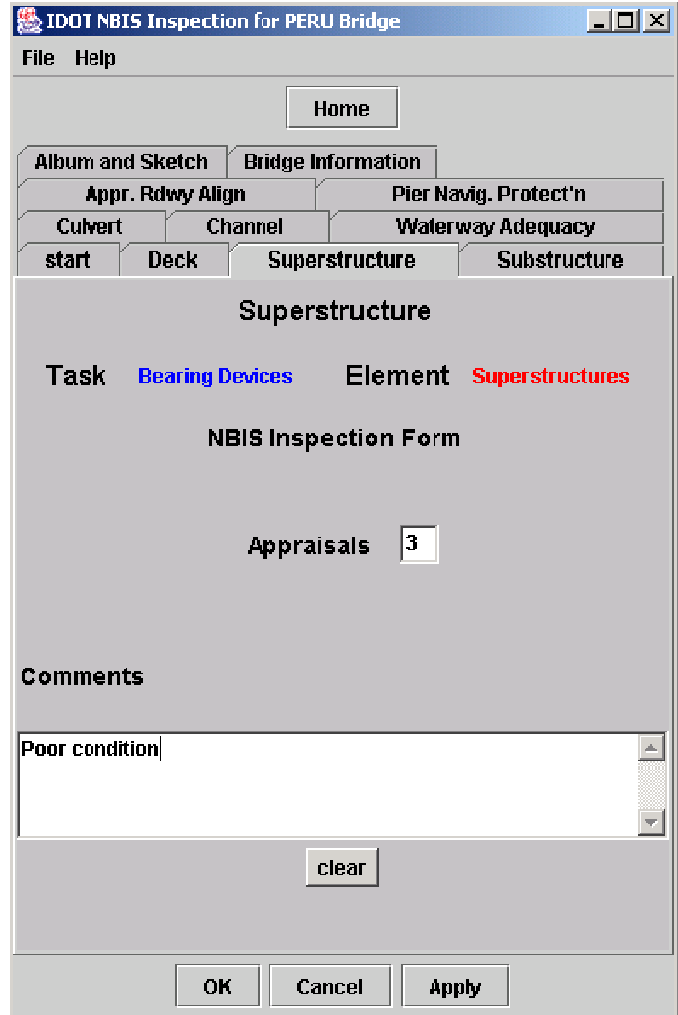
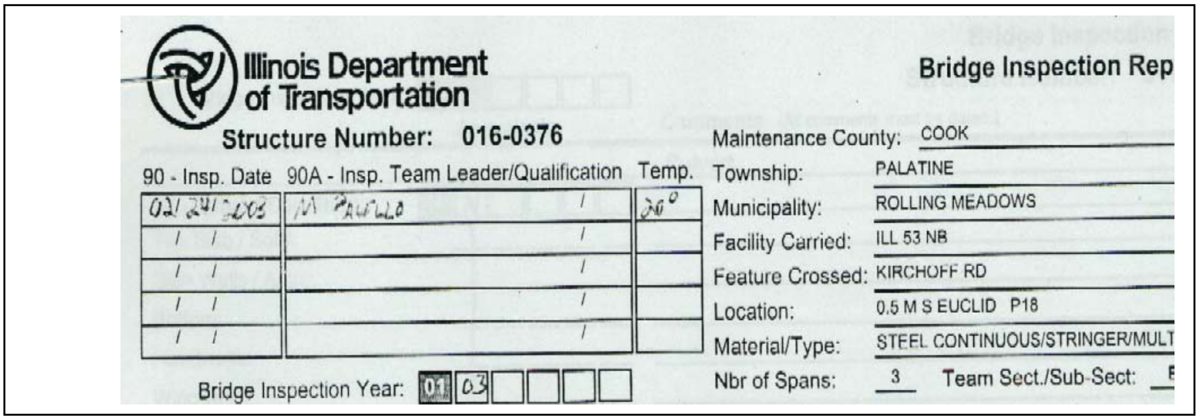


Figure 8. Screens of the Element Displaying and Inspection Processing

4.6. Field Testing the XML Interface

A preliminary evaluation of the system was conducted with District 1 bridge inspectors. The bridge used as a field test example is a three-span bridge built in 1962. It has steel continuous multi girders, with seated type joints over the end of the first and third spans. The general information such as bridge name and location, are recorded in the Bridge Inspection Report (MI), as shown in Figure 9.



Illinois Department of Transportation

Bridge Inspection Rep

Structure Number: 016-0376

90 - Insp. Date	90A - Insp. Team Leader/Qualification	Temp.
02/24/2003	M PAULLO /	20°
/ /	/	
/ /	/	
/ /	/	
/ /	/	

Bridge Inspection Year: 01 03

Maintenance County: COOK
Township: PALATINE
Municipality: ROLLING MEADOWS
Facility Carried: ILL 53 NB
Feature Crossed: KIRCHOFF RD
Location: 0.5 M S EUCLID P18
Material/Type: STEEL CONTINUOUS/STRINGER/MULT
Nbr of Spans: 3 Team Sect./Sub-Sect:

Figure 9.Bridge General Information Recorded in Current IDOT Bridge Inspection Report (MI)

In this field test, a blank bridge information form is called by the IDOT NBIS bridge inspection system. Inspectors filled in all of the necessary background information for this bridge, as shown in Figure 10. Among these pieces of information, the inspection date and the name of the inspector are critical and change from time to time. Other information for a particular bridge is fixed and can be generated as a permanent form and stored in the bridge management database to be called at anytime.

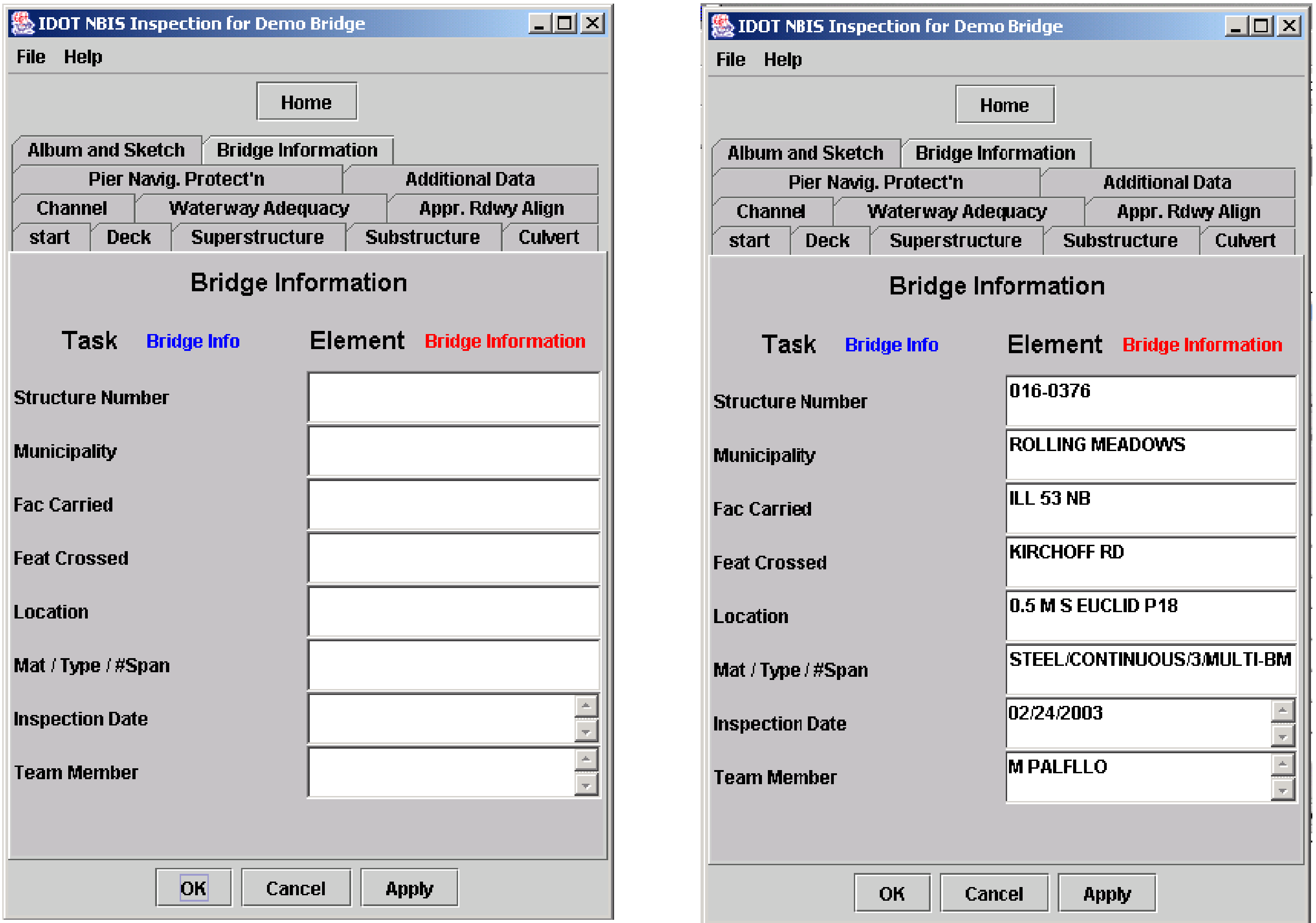


Figure 10. Background Information Collected in the Field Test by NBIS System

To start inspecting the bridge elements, like the deck, click on the deck tab on the main window shell. The detailed sub-elements menu of each element is displayed on the screen (see Figure 11). The deck element has eight sub-elements: *Wearing Surface, Parapets/Bridge Railings, Curbs, Median, Sidewalks, Drain System, Light Standards* and *Expansion Joints.* When starting the inspection with one element, the inspector can freely select a sub-element by drawing the mouse on the name of each sub-element and clicking on the "OK" button. In this field example, inspector rated the existing four sub-elements and left the other four in the menu list "N".

The existing paper form for the IDOT NBIS inspection, as shown in Figure 12, provides a schematic frame that can be easily implemented. Figure 13, Figure 14, Figure 15 and Figure 16 present the completed deck inspection procedure in this field test. Each screen reflects a particular inspection action for the corresponding inspection.

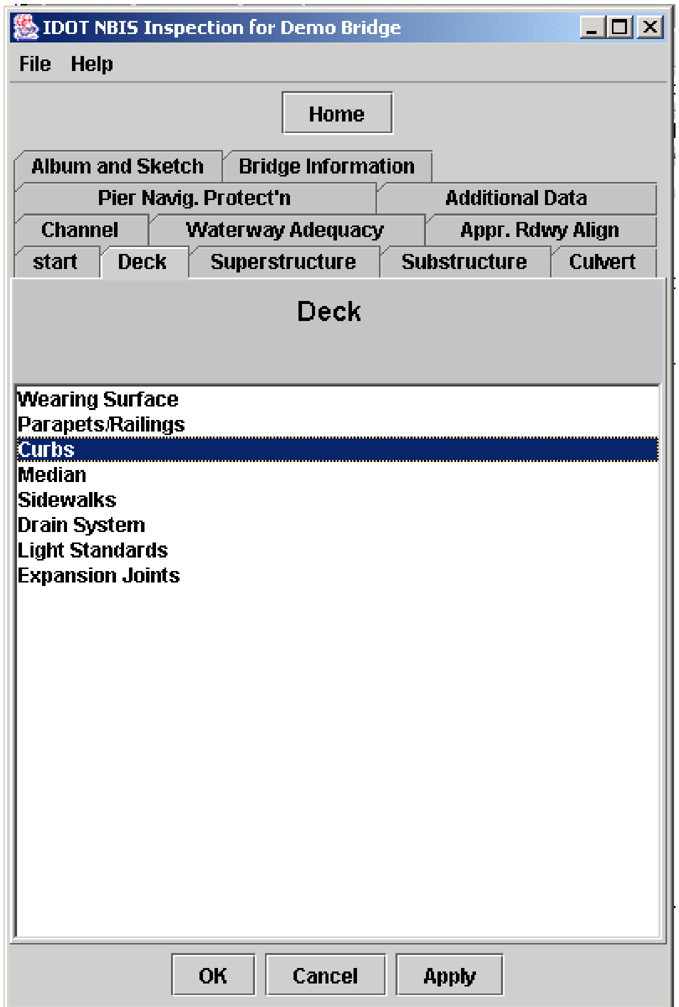


Figure 11. Deck Sub-Elements Menu

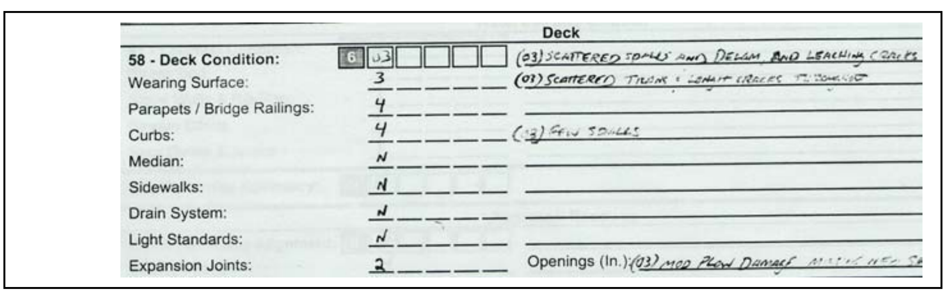
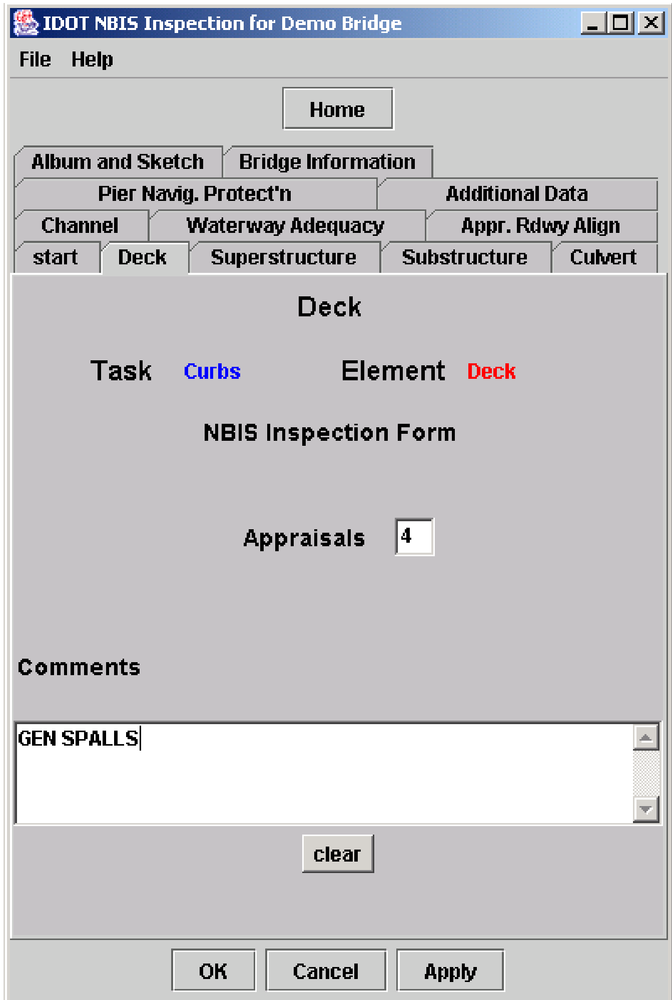


Figure 12. IDOT NBIS Inspection - Deck Elements



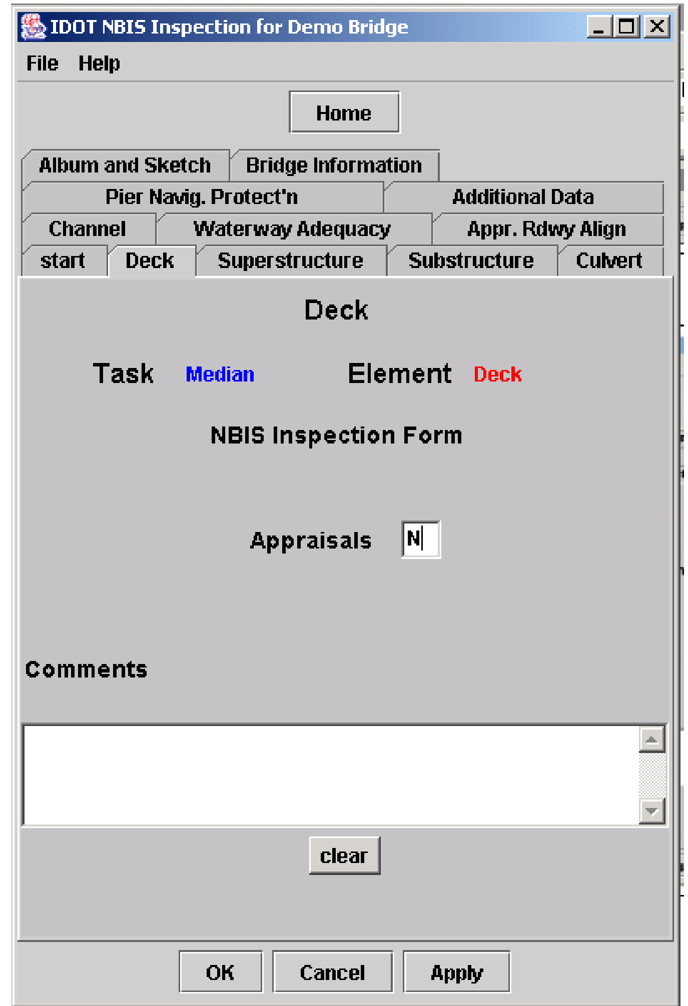


Figure 13. Deck Sub-Element Inspection – Curbs and Media

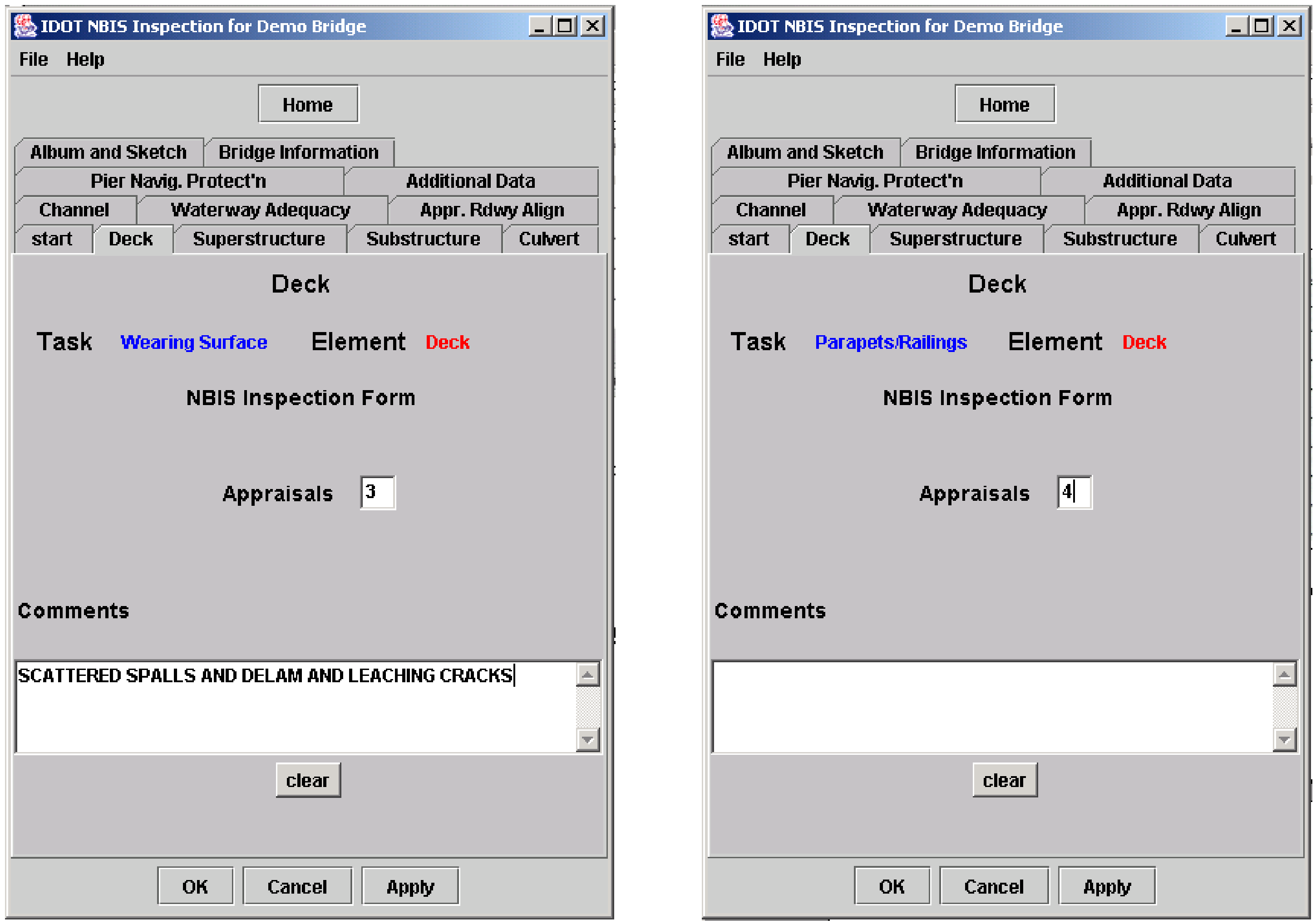
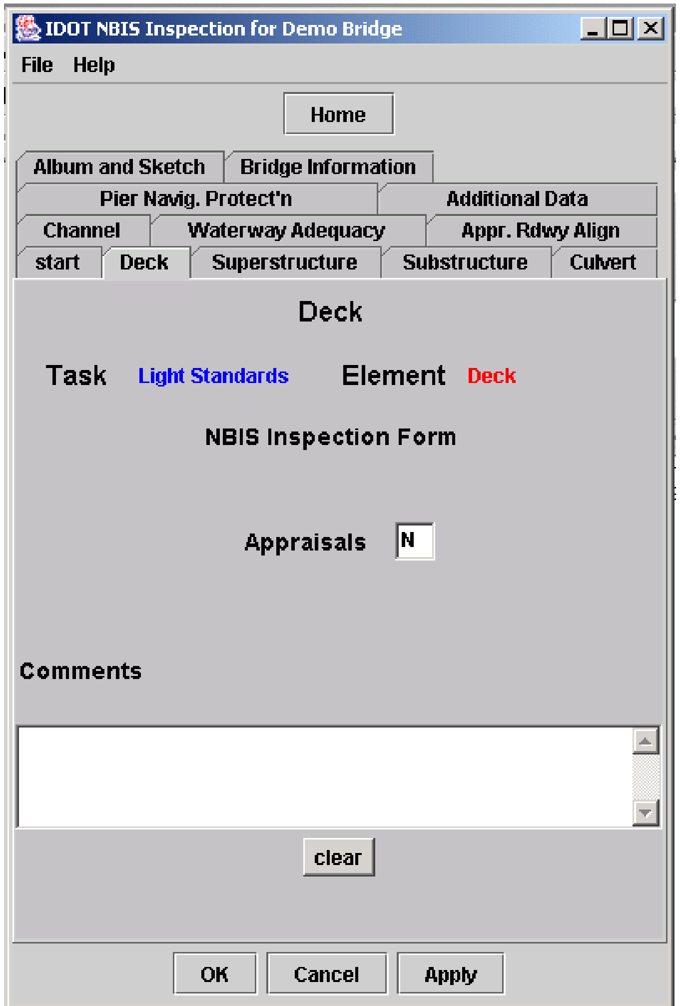


Figure 14. Deck Sub-Element Inspection - Wearing Surfaces and Parapet Railings



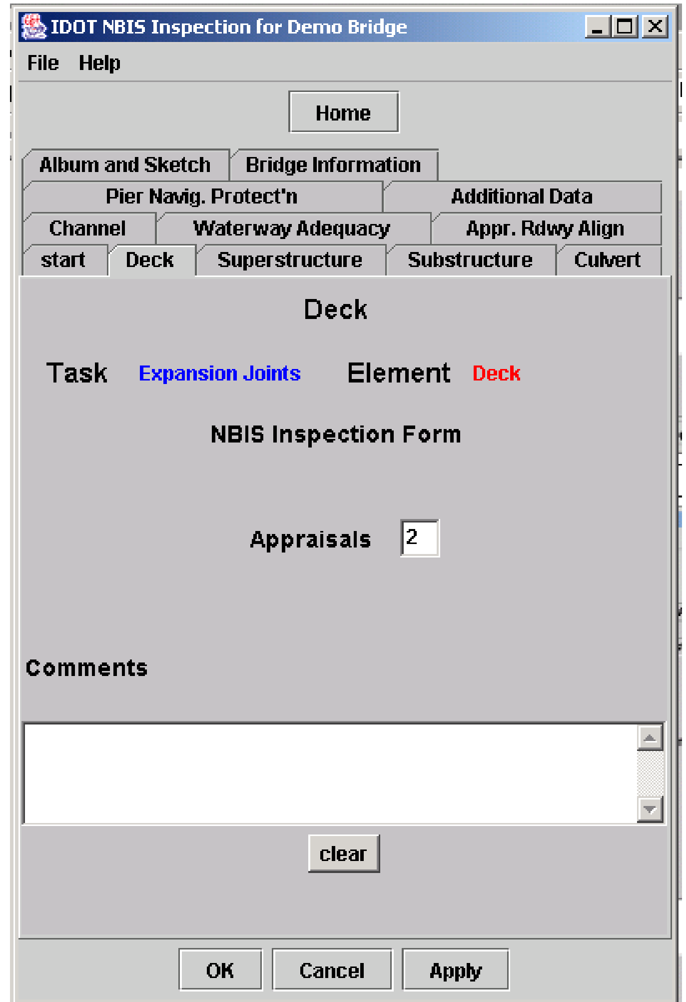
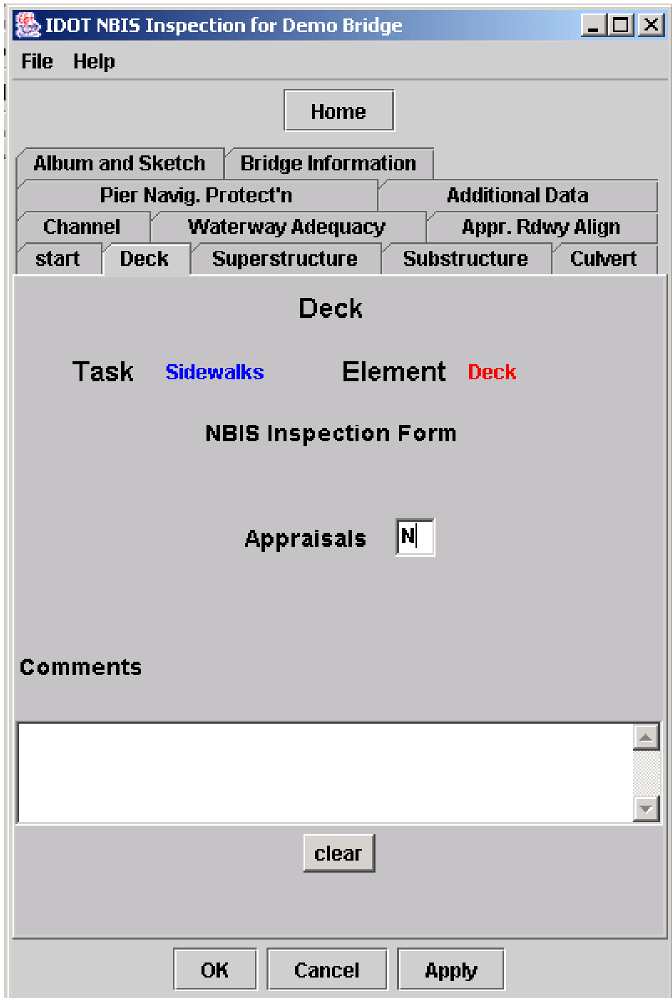


Figure 15. Deck Sub-Element Inspection – Light Standards and Expansion Joints



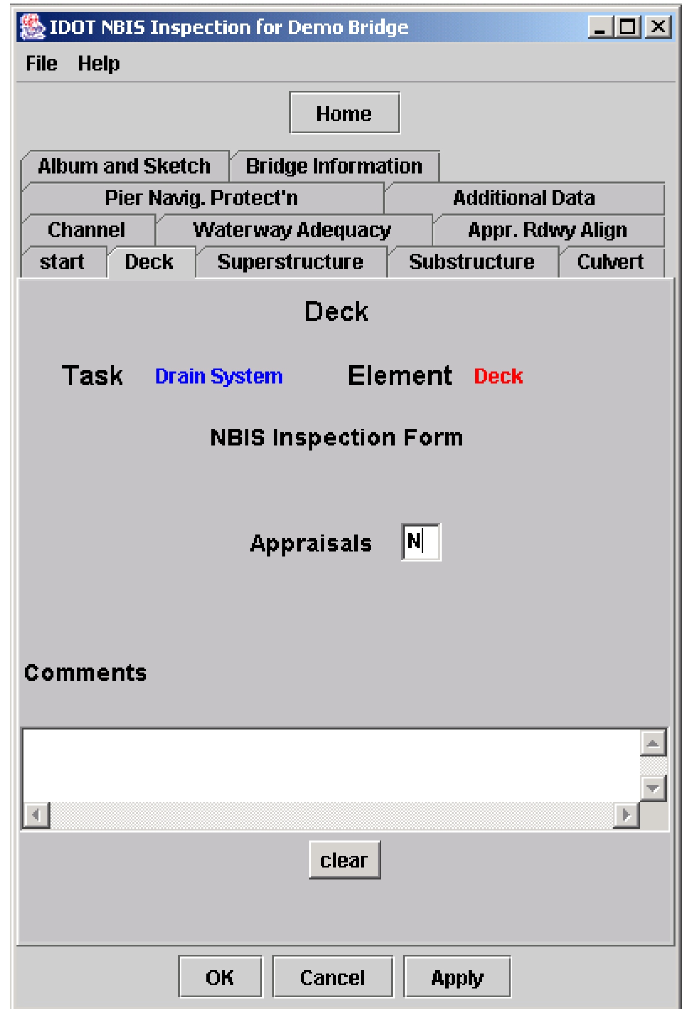
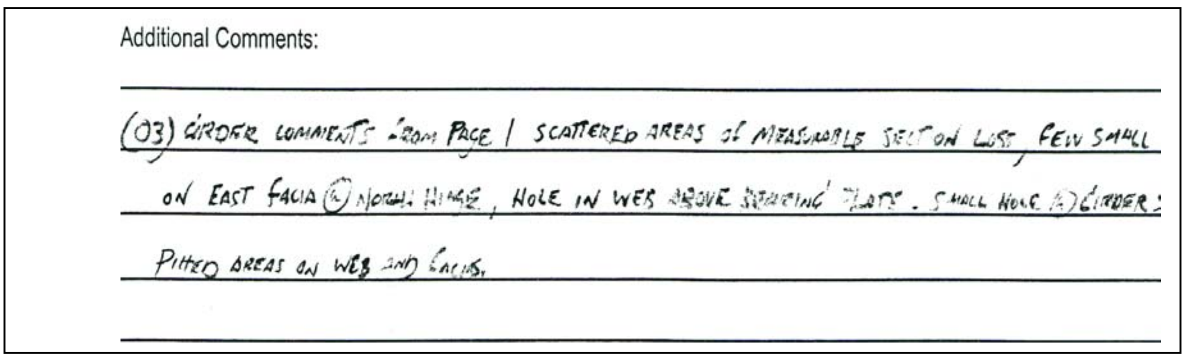


Figure 16. Deck Sub-Element Inspection – Sidewalks and Drain System

Although inspectors rate all of the sub-element conditions, only the condition state and the related comments of the main elements are uploaded to the IDOT NBIS bridge management system. Other collected data provides reference information for the later inspections. Thus, it is necessary to create a specific interface for collecting and displaying the inspection date, the condition states, and comments relating to the detailed defects of each element.

Additional Information

Besides the general information, such as appraisals and comments that were filled in the inspection form, the inspector wrote down some additional comments in the space provided on the forms. This part of the paper form is scanned and shown in Figure 17.


Additional Comments:

(03) GIRDER COMMENTS FROM PAGE 1 SCATTERED AREAS OF MEASURABLE SECTION LOST. FEW SMALL ON EAST FACIA (@) NORTH HINGE, HOLE IN WEB ABOVE STIFFENING PLATE. SMALL HOLE (@) GIRDER 2 PITTED AREAS ON WEB AND FACIA.

Figure 17. Additional Comments in IDOT NBIS Inspection Paper Form

Significant additional data was recorded in the IDOT NBIS inspection system as the “Additional Information” collection task. This task provides enough space to collect the kinds of information that is either not listed inside the main inspection tasks or will change frequently. As a result, the screen with the above additional comments displayed in the previous figure is as shown in Figure 18. These data are saved to the inspection report, as well.

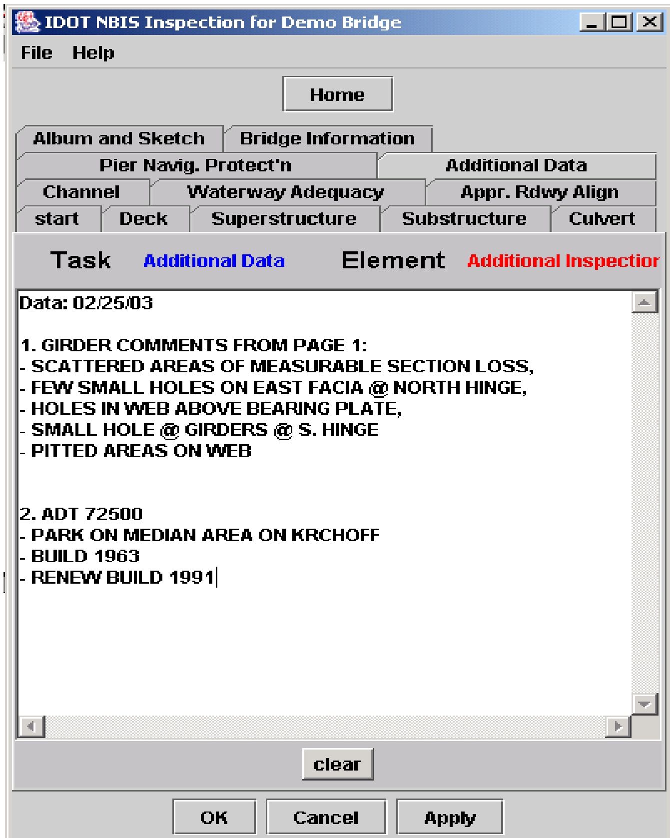


Figure 18. Screen of Processing Additional Inspection Data

Generate an XML Inspection Report

After all of the inspection tasks are done, the inspector clicks the "Save" button on the menu bar. A new XML file is generated (see Figure 19) with the data that was entered. This file has a well-organized structure and can be converted to a database file or a report form.

```
<InspectionElements>
<InspectionElement name="Deck" type="Bridge Deck">
        <InspectionResult time="7/9/2002">
 <CollectedData type="IMAGE" value="C:\bridge\bridge5.jpg" />
        </InspectionResult>
        <InspectionResult time="7/9/2002">
            <CollectedData type="IMAGE" value="C:\bridge\bridge10.jpg" />
        </InspectionResult>
        <InspectionResult time="7/9/2002">
            <CollectedData type="IMAGE" value="C:\bridge\bridge7.jpg" />
        </InspectionResult>
        <InspectionResult time="7/9/2002">
            <CollectedData type="SKETCH" value="C:\bridge\joint-sketch1.jpg" />
        </InspectionResult>
        <InspectionResult time="7/9/2002">
            <CollectedData type="SKETCH" value="C:\bridge\joint-sketch2.jpg" />
        </InspectionResult>
        <InspectionResult time="7/9/2002">
            <CollectedData type="SKETCH" value="C:\bridge\joint-sketch3.jpg" />
        </InspectionResult>
        <InspectionResult field="Wearing Surface" time="2/14/2003">
            <CollectedData type="COMPOSITE" value="and { , 3, SCATTERED SPALLS AND
DELAM AND LEACHING CRACKS }" />
        </InspectionResult>
        <InspectionResult field="Parapets/Bridge Railings" time="2/14/2003">
            <CollectedData type="COMPOSITE" value="and { , 4,  }" />
        </InspectionResult>
        <InspectionResult field="Curbs" time="2/14/2003">
            <CollectedData type="COMPOSITE" value="and { , 4, GEN SPALLS }" />
         </InspectionResult>
         <InspectionResult field="Median" time="2/14/2003">
            <CollectedData type="COMPOSITE" value="and { , N,  }" />
         </InspectionResult>
         <InspectionResult field="Sidewalks" time="2/14/2003">
            <CollectedData type="COMPOSITE" value="and { , N,  }" />
         </InspectionResult>
         <InspectionResult field="Drain System" time="2/14/2003">
            <CollectedData type="COMPOSITE" value="and { , N,  }" />
         </InspectionResult>
         <InspectionResult field="Light Standards" time="2/14/2003">
            <CollectedData type="COMPOSITE" value="and { , N,  }" />
         </InspectionResult>
         <InspectionResult field="Expansion Joints" time="2/14/2003">
            <CollectedData type="COMPOSITE" value="and { , 2,  }" />
         </InspectionResult>
 </InspectionElement>
```


Figure 19. Inspection Report in XML Style for IDOT NBIS Inspection

5. DISCUSSION OF RESULTS

The literature review, interviews, surveys, field observation, software development and field-testing presented in the previous chapters serve as a foundation for recommendations to Illinois Department of Transportation regarding the processes, systems and hardware that support bridge inspection and assessment. This chapter provides a synthesis of the research, development and information gathering in terms of technology adoption and acquisition, non-destructive testing technology, data acquisition technology, system development and control, electronic inspection forms, training, system support and quality control, and equipment.

5.1. General Observations Related to Technology

Field personnel are open to new technology and opportunities to improve the bridge inspection process. However, any changes should be in the context of the existing process. That is, they should not change how the inspectors do their job but make their work either easier or provide tools to enhance the quality and consistency of the inspections, and communication of information. Introduction of any new technology should include not just the acquisition of technology but a well-defined plan to address the following issues:

- **Interfacing the technology with existing systems**: IDOT has many legacy computer systems. Existing systems provide access to other types of data, meet federal reporting requirements, and update IDOT's internal databases. Entering duplicate information, and working with inconsistent or obsolete data is frustrating and counterproductive. Providing user-friendly interfaces to existing systems and data is critical to the successful adoption of new technology.
- **Maintaining and updating the technology**: Both software and hardware upgrades occur over time. Maintaining and updating the technology requires a strategy for introducing upgrades and ensuring compatibility among the technology and various systems.
- **Initial and ongoing training**: Personnel changes, and hardware and software upgrades mean that ongoing training is as important as the initial training when the technology is introduced.

The adoption of a new technology is not simply a matter of introducing the technology but planning for its use over the life of the process or the technology.

5.2. Observations Related to Non-destructive Testing Technology

With the exception of dye penetrant and mag-particle, non-destructive testing and evaluation is seen with significant distrust and skepticism. At the same time, the majority (but not of all) of the people we spoke with were not very familiar with NDE/NDT and potential benefits. Many individuals have had bad experiences with immature technologies or insufficient knowledge of the specific technology. There is also the problem that it is not clear how to fit NDE/NDT into the existing process. That is, there is no "place " to put the data.

On the other hand, this field is rapidly changing. It is appropriate to explore new technologies, recognizing that adoption of such a technology must follow the general recommendations outlined above. This requires strategies at several different levels:

- Developing new NDE/NDT training modules for inspectors and bridge staff. The training should address:
    - The differences between an evolving technology and a mature technology.
    - Strengths and limitations of NDE/NDT
- NDE/NDT methods
- Providing an environment that encourages exploration of new technologies and sharing of experiences.
- Exploring strategies for integrating NDE/NDT data into the inspection process. The electronic inspection forms can easily be modified to include such data.

5.3. Observations Related to Data Acquisition Technology

While a clipboard, paper and pen are the tried and true tools for data acquisition, there is a genuine interest among inspectors to try a more sophisticated method for electronic data entry that would support easy "uploading" of data, seamless access to historical data and appropriate for field use. The inspectors recognize that advances in technology mean that their "Apple Newton" experience may not be relevant. We recommend exploration of a wide range of devices including both laptops, tablet PCs and PDA's (personal digital assistants).

Most importantly the technology acquisition process must embrace the following steps:

- Integrate existing systems in a seamless way
- Acquire hardware, and software including communication hardware in a systematic timely manner.
- Provide comprehensive training to users once the technology is available but before they are expected to deliver results
- Plan for maintaining and upgrading the technology and ongoing training.

5.4. System Development and Control

In all the states we visited, the bridge division played a leadership role in defining the system needs, developing and maintaining the systems. The systems were developed to address the needs of the bridge unit and each state worked around issues and problems to obtain a fully functioning system.

In all cases, the bridge unit claimed ownership of bridge data. This is data that they produce or collect and that they use. In every state visited, they were committed to tying this data to the decision making process, although the degree to which this is currently done varied significantly and no state can honestly say that their bridge inspection data was fully supporting the decision making process, although they all indicated that this was a goal.

5.5. Prototype Electronic Bridge Inspection Forms

The prototype XML based inspection forms were favorably received by District 1 bridge inspectors. Ideally we would have liked to test the field use of the forms using a PDA, a Tablet PC and a laptop computer for data acquisition. However, IDOT contract restrictions precluded the acquisition of the appropriate equipment.

Based on our discussions with the IDOT bridge inspectors and interactions with the bridge inspectors in other states, we believe that the use of the Tablet PC or laptops in the field offer the most flexible, accurate and reproducible approaches to data entry. The inspectors are able to enter the data as soon as they collect it, they have a device that is easily moved between the office and the field, and they have easy access to an array of historical data. Most bridge inspectors will not take the data entry device onto the bridge with them because they like to keep their hands free and they are concerned with dropping the device. Therefore, there is little to be gained from the compactness of the PDA.

5.6. Training, System Support and Quality Control

Training and system support are key to ensuring the proper use and functioning of the system. The initial introduction of a new system requires the acquisition and installation of hardware and software, and training. It is important that all three components occur in a coordinated timely manner rather than piecemeal. Consideration must also be given to system upgrading and ongoing training. This includes access to technical support.

Based on discussions with several states, training and system support are believed to be the critical elements of quality control.

5.7. Equipment

Properly functioning state of the art equipment is also essential to an efficient, consistent and comprehensive bridge inspection program. All states that we visited provided their bridge inspectors with offices on wheels. These “offices” included paper files, a laptop or other portable computer, digital cameras, scanners, and printers, as well as the typical equipment required of a bridge inspector (dye penetrant, ladders, hammers etc). Computer equipment was state of the art with appropriate peripherals for connecting to the central office, delivering printed versions of reports and photos, integration of sketches and photos into the bridge inspection report and supporting data entry.

Budget constraints, and the scale of operation in Illinois aside, the equipment we have seen in the district offices is antiquated and barely functional. Updating equipment and providing mobile offices would greatly enhance inspection productivity.

6. SUMMARY AND CONCLUSIONS

Because of the importance of bridges in the transportation network and the budgetary constraints on maintenance, repair, and rehabilitation activities, a comprehensive bridge inspection support system is critical to support decision-making. The inspection support system must be tailored to match the requirements of the specific inspection activity to support the data collection process effectively and efficiently.

6.1. Summary

The review of the literature and IDOT practices, the survey of other states, and the in-depth field visits to Maryland, Montana, New York and Pennsylvania provided insight into a broad array of experiences and bridge inspection practices.

The literature review demonstrated that there is a wide array of technologies applicable to bridge inspection and management. The literature review also showed that these technologies are rapidly evolving. However, there were no emerging technologies that could be identified as the next generation of bridge inspection technology. It is also clear that the adoption of any new technology requires a comprehensive approach including training, technology support and planning for future upgrades. New technology must also be tailored to the needs of the organization using the technology.

Telephone interviews and field visits to IDOT district offices in the Fall of 2000 provided a snapshot of IDOT bridge inspection practices, and the perspectives of the bridge inspectors and district bridge engineers. Some observations are key to setting the directions for the project:

- Districts follow similar practices
- Quality control focuses on rating a bridge in a worse condition than the actual condition
- Inspectors and bridge management engineers are open to new technology
- Resources are limited
- New technologies should replicate and enhance the existing process.
- Ten different bridge management tools and databases were identified.
- The systems and databases seem to be in a constant state of flux.

- There are significant differences in the quality and functionality of the hardware and software in the district offices and who has access to the wide array of bridge related databases.

Each of the fifty state departments of transportation in the United States was surveyed to identify innovative and relevant inspection practices and technologies. Twenty-seven states responded to the survey. Of the responding states, fifteen indicated that they were using innovative technologies. Follow-up phone calls were made to these fifteen states. Based on the review of the literature, surveys, and telephone interviews, four states were identified as using technology of relevance to Illinois. These states are:

- *Maryland:* Maryland is using laptops in the field with digital photos.
- *Montana:* Montana is using a web-based system for data entry and data management. This system is similar to the proposed system in Illinois.
- *New York:* New York has the most advanced integrated system for data entry and management. It is comprehensive and flexible so there are opportunities to include new data from bridge monitoring or non-destructive testing. The process NYSDOT uses for bridge inspection is very similar to IDOT.
- *Pennsylvania*: Pennsylvania is using handheld devices for data entry and transfer.

The research team then visited each of these states. All four states have customized software for field data entry that interfaces with the bridge management systems or databases that are used to support decision-making. Maryland, New York and Pennsylvania do their data entry in the field using laptops (Maryland and New York) or a pen based system (Pennsylvania). In Montana, inspectors used a web-based system for data entry. In all four states, the bridge section or division controls the process and has demonstrated a leadership role in developing systems to meet the needs of the organization as well as cater to the inspectors.

Finally, an XML version of the IDOT bridge inspection forms was developed for use in the field. These forms were developed using a Java Inspection Framework (JIF), which is a tool to support inspection. The end result of this application is an interface for use by bridge inspectors in the field. This interface provides the inspector with access to historical data and past inspections. Most importantly, it provides an electronic record of field notes that is easily transportable and widely accessible. The data entry form was developed with input from the District 1 bridge inspectors.

6.2. Conclusions

The need for improved field data management for bridge inspection and assessment was underscored in comments from inspectors and bridge maintenance engineers, and interviews with inspectors and bridge engineers in other states. Resources constraints aside, bridge professionals in Illinois must take a proactive approach to the management, and control of bridge data. In the long term it is anticipated that this will reduce the life cycle costs of bridges, as the process will be supported by easily accessible, consistent data.

Using the Java Inspection Framework (JIF), an inspection support system was developed that provides a helpful tool and a schematic structure to assemble necessary components of an inspection support system together. A customized interface or specific interfaces can easily be created.

IDOT district bridge maintenance personnel tested the IDOT NBIS inspection system. Some changes were incorporated in the program, as it will be developed based on the recommendations and suggestions of the IDOT maintenance engineers and bridge inspectors. Some of the benefits of using the field inspection support system are presented in the following parts:

- **Completeness**: The IDOT bridge inspection system shares the inspection knowledge, tasks and instruments for every bridge. The inspection knowledge describes the relationship of collected data and their effects on the inspection results, while the inspection task presents the possible activities that will be conducted during an inspection. The inspection system supports the detailed field inspection tasks that are required in the IDOT routine bridge inspection procedure. It covers nearly all of the bridge elements, and keeps records of their condition states on both the screen and in the newly generated report. Inspection instruments such as the data collection interface, photos or sketches and the bridge information forms are provided by the system to facilitate the inspection process.

- **Simplicity**: Collecting and storing the inspection data using computers simplifies the inspection process. An IDOT bridge inspection support system implemented using XML based script demonstrated the links among inspection elements, knowledge and tasks. Using XML meant that the developer required fewer computer programming skills but enough knowledge of the bridge structures and inspection process. The system has an organized structure, thus making it is easy for software maintenance personnel to add, revise or delete some specific tasks or knowledge regarding the requirement of the inspection. Providing a clear structure with the tab shell, inspectors in the field can simply draw the mouse on the task that he/she would like to proceed and click the corresponding button. Meanwhile, the function of retrieving the previous inspection record will ease the work of condition state rating.

- **Adaptability and flexibility**: Based on Java, the inspection system is adapted to most hardware platforms, such as laptop computers and pen-based computers, without any additional software, but only the Java run-time environment. The knowledge file in the system decides the name of each inspection element and the appropriate information contained by it. The tasks part decides which inspection element will be inspected and how to arrange the detailed inspection activities. Based on the fixed knowledge and tasks, the inspection instrument may have multiple interfaces. These features offer each IDOT district flexible inspection options to process the practical inspection. They may either follow the uniform inspection interface or create their own.

7. RECOMMENDATIONS

Our overall recommendations based on the research conducted for this project fall into four categories. The first are recommendations related to technology and equipment. The second are organizational issues that must be addressed before IDOT proceeds to develop additional inspection support systems. The third is the process for implementing and supporting systems in the field. The final category includes specific research questions that should be explored in the context of an integrated interface for bridge inspection and assessment data.

7.1. Technology and Equipment

Assuming resources are available, bridge inspectors should be provided with state of the art equipment to support the data collection process, to facilitate the seamless transfer of not just data but supporting information, to encourage the timely entry of data, and to encourage consistency. This includes such basic equipment as vehicles equipped with computers, printers, scanners, electronic media, network connections and digital cameras, along with the software to support data entry and the exchange of information between the field, district offices, and central office. The concept of a "modern office on wheels" is successfully used in three of the four states we visited, and is limited by climate in the fourth state (Montana). The equipment must be maintained in good working order and upgraded as appropriate.

7.2. Organizational Issues

IDOT Bureau of Bridges and Structures must take a leadership role if an integrated system is to be developed that addresses the needs of both field personnel and decision makers. Although many of the functions are decentralized, the control over data, information and systems needs the vision and leadership of those with a vested interest in the process, if the next generation of data entry systems is to be useful, functional and effective. This includes defining what that vision is and finding the resources to support the development of the system and its continued support in the field.

A careful analysis of the tradeoffs between the effort expended to collect and store data, the investment in technology and the value of the data also needs to be made.

7.3. Process Issues

A successful bridge inspection and assessment system has four elements:

- Hardware
- Software
- Maintenance and upgrading of the hardware and software
- Training and ongoing support

Based on the experiences within IDOT and at other states, we recommend that all four elements must be in place to ensure success. That means that training, support and upgrading is not a one-time effort but a commitment to continue the process.

7.4. Future Research

The inspection support systems explored in this project are just the preliminary steps in the process of electronically collecting and recording information for IDOT bridge inspections. The procedure can be further developed and simplified in the future as the technology advances. On the basis of the research presented herein, the future research can be done to improve the quality and the usability of the inspection support system focusing on the following issues:

- **Report generation:** Due to the time and knowledge limitation, the current implementation of the inspection support system does not provide report generation functionality. However, it can generate an XML file that records all of the activities and the inputting data during the inspection process by JIF default features. As IDOT requires their inspectors to submit a report after they perform the inspection and upload it to IDOT central office Bridge Management System (BMS), it is necessary to convert the XML file to a database file, which is compatible to the IDOT BMS. Fortunately, the XML document is database formatted. It is possible to be an XML file and convert it to a database document by some program written by Visual Basic or Java.

- **Pen-Based Application**: Installing and processing the inspection support system on a pen-based or hand-held device require a pen-based version of Java run-time environment. Use of a pen-based computer would eliminate the use of a keyboard and greatly release the inspectors' hand from carrying heavy devices. The inspection systems described in this research adapted for the laptop application well yet has not been tested on any pen-based or hand-held devices. Future research will be conducted on installing the inspection support system on these devices and conducting field tests.

- **Voice Recognition:** Using this technique, the inspector will be able to "talk" the data into a computer. This requires training of the voice recognition system to a particular inspectors speech patterns and the use of a vocabulary relevant to bridge inspection. This would eliminate the use of either a keyboard or a pen for input of the information. The voice recognition function already exists in JIF as its optional feature. However, some hardware on the computer may not support this application.

- **The Creation of Web Application:** Using a web-based inspection application is a popular method for bridge field inspection today. Inspectors can access the central/district office bridge management database by downloading and uploading the data by Internet via web browser. As JIF is developed based on the technologies of Java Application, the IDOT inspection support system is a stand-alone application and cannot be used for web-connection.

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APPENDIX A.

ACRONYMS AND ABBREVIATIONS

AASHTO – American Association of State Highway and Transportation Officials

ACCESSS™ – A commercial database system

BAMS – Bridge Analysis and Monitoring System

BARS – Bridge Analysis and Rating System

BIPPI – Bridge Inspection Pen Interface

BME – Bridge Maintenance Engineer

BMS – Bridge Management System

BPT – Bridge Project Tracking

DOT – Department of Transportation

EDC – Electronic Data Collectors

EMR – Electronic Medical Records

FHWA – Federal Highway Administration

GIS – Geographic Information System

GPR – Ground Penetrating Radar

HERMES - High-Speed Electromagnetic Roadway Measurement and Evaluation System

IDOT – Illinois Department of Transportation

IRIS – Illinois Roadway Information System

ISIS – Illinois Structures Information System

ITRC – Illinois Transportation Research Center

JIF – Java Inspection Framework

MMI – Maintenance Management Information System

NBI – National Bridge Inventory

NBIS – National Bridge Inspection Standards

NDE – non-destructive evaluation

NDEVC - Non-Destructive Evaluation Validation Center

NDT – non-destructive testing

NBIS – National Bridge Inspection Standard

OP&P - Office of Planning and Programming

PCS – Pre-Construction Status System

PDA – personal digital assistant

PPS – Planning and Programming System

RAC – Research Advisory Committee

SIMS – Structure Information Management System - – An ACCESS database derived from ISIS

SQL – Structured Query Language

TRP – Technical Review Panel

UTC – Urban Transportation Center

WINBOLTS – Windows Version of the Bridge Online Transaction System

XML – eXtended Markup Language

APPENDIX B.

LITERATURE REVIEW

B.1. Introduction

This comprehensive literature review of bridge inspection and assessment procedures cover inventory, condition assessment and inspection technologies as well as data management. The literature review is presented in three parts. The first part is a synthesis of the literature in each of fours areas:

- State inspection manuals
- Tools and Techniques
- Inspection Data and BMS
- Technologies from Other Areas
- Nondestructive Testing Techniques
- Monitoring and Damage Assessment

The second part lists the sources found in each of the areas. The third part is an annotated bibliography of selected sources.

The synthesis is intended to provide an overview of the state of the art and the state of the practice to serve as a foundation for subsequent stages of this work.

B.2. Synthesis of the Literature

Manuals

To obtain a sense of the state of the practice of bridge inspection, manuals were obtained from Illinois as well as five other states:

- State of California: Caltrans – ABME Structure Maintenance Procedures
- State of Florida: FDOT – Bridge and Other Structures Inspection and Reporting Procedures Manual
- State of Illinois: IDOT – Structure Information and Procedure Manual
- State of New York: NYSDOT – Bridge Inspection Manual (1997)
- State of North Carolina: FHWA – Bridge Inspector's Training Manual 90 and Recording and Coding Guide
- State of Texas: TxDOT – Bridge Inspection Manual (2001) State of Texas: TxDOT – Bridge Inspection Manual (2001).

Table 7 summarizes the approach to bridge inspection as documented in the manuals. The table indicates common practices among the states, particularly when dictated by federal regulations. It is important to note that the manuals do not necessarily convey practice or function. For example, California does not do NBI inspections but meets the requirement of NBI reporting by using an FHWA approved conversion form PONTIS® data to NBI data [REF].

In terms of data collection all of the states reviewed follow the FHWA requirements of FHWA by performing routine biennial inspections. Although California does not collect NBI data, all states collect bridge inventory data and additional information exceeding that required by NBI. The collected information is entered into the database of each State DOT and can be updated.

In terms of nondestructive evaluation (NDE), only the states of New York, Florida and North Carolina have NDE procedures in their inspection manuals, but not in detail. Among them, State of New York has the clearest description but they just list two types of NDE (one is dye-penetrant testing and the other is magnetic particle testing). Other State DOT's encourage or allow the use of NDE but no inspection trigger/requirement is documented.

In terms of bridge management systems (BMS), based on the manuals, each State DOT is required to enter the collected information into their databases, but not all of them have the link to bridge management system. Some just use the BMS database.

Tools

To obtain an idea of what tools were being used in the bridge inspection and maintenance activities. These tools that we came across in our literature review could be broken down into two categories: (1) data storage devices, and (2) non-destructive evaluation (NDE) devices.

Before we explore these two types, the need for tools must be established and what we mean by tools must be defined. Many publications discuss the reliability of visual inspections. The goals of these publications are to provide an overall measure of the reliability and accuracy of routine and in-depth inspections and to study the influence of human and environmental factors on inspection reliability. Much of this research is done by questionnaires distributed to the different state DOT's (Washer 2001). The conclusion of this research is that the visual inspection inherently has it problems with reliability because of multiple inspectors but with tools these problems could be reduced. Therefore, by tools we mean devices to improve the accuracy, consistency and reliability of bridge inspection, as well as simply making the task faster and easier for the inspector.

Table 7. Comparison of State Inspection Procedures

State	Routine Inspections							In-Depth Inspections				
	Frequency	NBI	Element Level Inspection	NDE	Customized Forms	Links to Bridge Management	Supplemental Requirements	Frequency	Trigger	Requirements	Documentation	Rating
California	Biennial	No	Yes	No [1]	Yes	Yes - PONTIS®	Earthquake	5 Years	Yes	Yes	Yes	Yes
Florida	Biennial [3]	Yes	Yes	Yes [2]		Yes - BMIS	Quality control	Not fixed [3]	Yes	Yes [4]	Yes	Yes
Illinois	Biennial	Yes	Yes	No [5]	Yes	Yes - PONTIS® (MMIS, ISIS)	No	6 Months [6] 12 Months	Yes	Yes	Yes	Yes 0-9
New York	Biennial	NA	No	Yes	Yes	Yes - NYSDOT BMS [7]	Photos, comments and/or sketches	Annual	Yes	Yes	Yes	Yes 1-9
North Carolina	Biennial	Yes	No	Yes [8]	Yes	Unknown	Underwater	2/4/8 Years	Yes	Yes	Yes	Yes
Texas	Biennial	Yes [9]	Yes	No	Yes	No [10]	Underwater	5 Years	Yes	Yes	Yes	Yes 0-9

Notes on the Table

1) The Area Bridge Maintenance Engineer is encouraged to employ the services to perform appropriate NDT to help locate and identify potential problem. No NDT procedures are mentioned in Caltrans Manual. (State of California)

2) Non-destructive testing (NDT) can be used to augment visual inspection. Generally, NDT is not practical for large-scale use on a bridge unless a defect has first been detected by visual means. NDT can be used to highlight or define the extent of the defect. (State of Florida)

3) The condition of a bridge's components, major features and the bridge posting rating establishes the frequency of inspection. Specifically, a rating of 5 or greater requires inspection every two years, 4 requires inspection every year, and 3 or less requires inspection every 6 months.

4) Requirements for in-depth inspections refer to "Inspecting Steel Bridge for Fatigue Damage" by John W. Fisher, Research Project No. 72-3 "Manual for Inspecting Bridges for Fatigue Damage Conditions", by John W. Fisher, Research Project No. 85-02, and "Inspection of Fracture Critical Bridge Members" FHWA-IP-86-26.

5) Although not documented in the Bridge Inspection Manual, Illinois follows similar practices to Florida with respect to NDT.

6) This frequency indicates the number of months between fracture critical inspections of a structure that has been designated as having fracture critical members. In practice these may actually be between 12 and 60 months. The actual frequency depends on the condition of the structure. (State of Illinois)

7) This database identifies all bridges and identifies all pertinent information about the bridges including dimensional and weight limitations and a record of all bridge inspections.

8) Special feature inspections for Ultrasonic and Non Destructive Testing are reported separately with a cover sheet that references this type of inspection. (State of North Carolina)

9) Texas captures additional information exceeding that required by the NBI. The data are also used to update the National Bridge Inventory File (NBI) for the FHWA. Once a year the complete Bridge Inventory Files for off- and on-system bridges are converted to the actual NBI format and submitted to the FHWA. (State of Texas)

10) ‘As of 2001, TxDOT has no formal Bridge Management System (BMS) in place. Some beta testing of the PONTIS® system, which is sanctioned by AASHTO, has taken place, but full implementation of this system is not imminent’. (State of Texas)

Data storage devices are those devices that can store visual inspection and text data on site. They may also have the potential of viewing old inspection reports on site to use as a comparison while rating the current conditions to increase the reliability of visual inspection. The data storage device most widely researched is the personal digital assistants (PDA). Typical data collection devices are documented in Table 8.

Many companies have dived into the mobile computing field. All of these companies have the goal of producing useful field products and software. These carefully designed tools should allow the user to reduce time spent entering data by hand and eliminate data entry errors. Also the user should have additional resources available to him on the product that allow for a higher quality inspection such as digital photos, old inspection reports, rating manuals, and etc.

One such company is Fieldworker from Toronto, Canada that has been involved in the field of mobile computing since 1995 (http://www.fieldworker.com/). They have provided services in the form of software solutions and technical help to over a hundred companies. These have included the California and Arizona DOT's.

Synchronization of data from the field provides many advantages as stated above such as timesaving and less error introduced into you databases. Fieldworker provides Data Synchronization solutions that support a variety of data exchange requirements, ranging from small groups of field users to large organizations using hundreds of mobile devices and providing a distributed data solution across multiple databases. Data instead of waiting to be entered for sometimes close to a year can now be instantly analyzed. Now the user of the system to use the most up to date information when making management decisions or running a bridge management program such as PONTIS®.

All different type of data can be collected such as simple checklist to digital photos. The electronic forms are the most interesting to the bridge inspection user. Other tools such as electronic signature data could be used for instance as a security to avoid claim of database corruption on individuals. Making data entry a traceable responsibility back to the user. In addition, a sketchpad could allow for graphical depictions besides photo that could illustrate a particular issue of the bridge.

The idea behind most of research related to data inspection for bridge inspection is to digitize the inspection form so that the Bridge Inspector will have the capabilities listed in Table 8 for inspecting and storing data and also being able to call up old inspection forms for comparison (Leung 1997).

These articles all point out that PDA type devices would reduce errors because data could be transferred automatically without the threat of transcription errors. Time saved is another big benefit of this type of system. Notes and sketches can be worked into the PDA to allow for the same capabilities as the paper based system. Most of the authors give us some background on the training needed for pen-based systems but are unable to give us long-term results of the system and the level of satisfaction with the system from the inspectors. They make the point that the digital forms should not differ dramatically from the paper-based inspection form in order to gain acceptance (Elzarka 1999).

Other data collection devices that were reviewed in the literature were speech recognition systems. These systems were only being used in the lab environment and somewhat promising because they have the potential for completely hands free inspection. The initial research showed similar error percentages while entering data into the speech recognition system compared to pen based system. The studies though promising were not statistically significant and were done in a controlled environment (Sunkpho, 2000).

Table 8. Data Collection and Entry Devices

Device, Tradenames, Reference	Advantages	Disadvantages
Personal Digital Assistant (PDA)		
Palm Pilot – www.palm.com/ Handspring – www.handspring.com/ Clie – www.sony.com	Portable Uses standard interface Transfer can be wireless Readily recognizes handwriting	Easily lost or misplaced Not always easily read in low light or high intensity sunshine Battery power
Wearable computers		
Xybernaut http://www.xybernaut.com/ MIA (Garrett et al, 1998) http://www.ices.cmu.edu/thrusts/edrc/flyers/mia.pdf	Uses hands free data entry allowing for greater mobility in inspection	System must be developed from ground up. Untested long-term bridge inspection environment
Bridge Specific Applications		
Trilon http://www.trilon.com/trilon/index.html	Portable Format set up for specifically for elemental PONTIS® Bridge Inspection PONTIS® coding and rating information available to inspector on device Data transfer to PONTIS® has already been developed.	NBIS inspection not included in format of device. IDOT has somewhat of a negative history with company that participated in Newton Apple program.

The papers that were reviewed began to give us a clear view of what was out there and provided a direction for our research. One should keep in mind this is only an initial investigation and that many more devices exist out there that could be applied to bridge inspection. The variety of equipment and platforms available for field data collection ranges from the simple pencil and paper to the 21^{st} Century wearable computer with speech recognition. The devices that we presented here in this literature review are all viewed as potentially to improve the accuracy, consistency and reliability of bridge inspection, as well as simply making the task faster and easier for the inspector. The reader should be aware that names of these tools sometimes overlap for instance PDA (Personal Digital Assistant), handheld computer, Palm devices, and ubiquitous computing. This is a new field and still developing and the language of the field has not yet caught up to the technology.

Inspection Data and BMS

Accurate and informative data representing the real-time condition of the bridges in the system inventory is critical to the effective use of bridge management systems (BMS). Inspection data is also being used in new ways (Roberts, 2000). New technology for data collection, storage and transfer not only addresses many of the constraints and concerns with the existing processes but provides additional condition data needed to make good decisions regarding the tradeoffs among maintenance, repair and rehabilitation strategies. 'Improvement of visual inspection procedures, innovation of nondestructive testing methods, and automated methods to gather and manage data is now highly encouraged.' (Hearn et al, 2000).

Visual inspection techniques are the primary methods used to evaluate the condition of the majority of the nation's highway bridges. Although all bridge inspectors have received the same NBIS training course, several factors such as environmental conditions, the human physical condition, and the inspectors' experience and performance can affect the inspection result. The Non-Destructive Evaluation Validation Center (NDEVC) of the Turner Fairbanks Laboratory conducted an investigation on the reliability of visual inspection. The investigation looked at both routine inspections and in-depth inspections. In routine inspections, there are great variability in element-level inspection results (especially condition ratings), inspection notes, and photographs taken by different inspectors. For in-depth inspections, the inspection may not yield any findings beyond those that could be noted during a routine inspection. The investigation showed that the inspection results were not consistently accurate and need significant improvement (Phares et al 2000, Phares et al 2001).

Non-destructive evaluation provides additional assessment data not available using visual inspection that is far more reliable then visual inspection. This technology is employed in conjunction with the three predominant materials, concrete, steel and timber, used in most bridges. A strategy of to integrate non-destructive evaluations (NDE) data with bridge management systems has been developed (Hearn 1998). Based on the interdependence of NDE methods and BMS specific NDE methods provide information on condition to management systems and this NDE data allows management systems to identify changes in condition of elements more precisely. Hearn introduced five condition ratings, ‘protected, exposed, vulnerable, attacked and damaged’ (Hearn, 1998) to assign the condition of CoRe elements[1]. Thresholds were defined for the raw NDE data in a standard way that they marked the barriers to different condition states. Detailed, quantitative data from NDE methods can be used by management systems for determination of conditions and for explicit modeling of deterioration. Hearn’s deterioration model considered transition probability for a condition state that is inversely related to the endurance of the stage of service life and the variability and uncertainty in the meaning of measurement. Hadavi (1998) also suggested the use of NDE to quantitatively measure condition. ‘Quantitative measures can then be compared with a limit state standard that uniquely determines the repair or maintenance strategy.’ (Sanford et al, 1999).

BMS manage and organize bridge inspection reports and keep track of inventory records to facilitate better decisions for both maintenance and rehabilitation. Currently there are gaps in the data collection efforts including data that are collected but not recorded, and data collection efforts that are duplicated for different functions. BMS does not provide any systematic procedures for selecting inspection tools. (Sanford et al, 1999) Hearn’s approach is to integrate NDE data into or with condition ratings, and to develop a link between BMS and analysis tools.

Technologies in Use

Technologies that are in use in various field environments can help us to develop realistic plans for IDOT Bridge Maintenance offices. One field that widely accepts the PDA technology is the medical community. The paper we read focused on the ambulatory health care and the effect PDA technology had on that field demonstrating the similarities to bridge maintenance activities (Barbash 2001). The fact that old records are extremely helpful to the health care provider and bridge maintenance crew in accessing health is one of the strong similarities between the two fields. In the ambulatory health care, Electronic Medical Records (EMR) are the equivalent of past bridge inspections (Barbash 2001). In both fields, access to these records are

[1] Commonly recognized elements are a term used by PONTIS® to standardize inspection data.

limited because they were not portable and user friendly. PDA devices are effective tools to address these issues. No longer does the doctor have to go to a desktop connected to the system and read the file or get a print out of what he or she thinks is important. He or she has all the information that influences decision making while with the patient. The bridge inspector would benefit from this same level of information at the bridge site. Another benefit to the health care field that PDAs provide is that it improves information sharing and requests for work. After the information is collected, since it as already in a digital format, all or parts of the information can be transferred to many different destinations without input into different databases. For example, information can be sent to medical records or to the pharmacist taking care of this patient's needs. In terms of request for work, a doctor could make an appointment for a patient for x-rays or laboratory work. These ideas are also applicable IDOT needs. The information collected at the bridge site is needed in more than one database and this transfer could occur automatically. An automated process could eliminate transcription errors. It is easy to envision an inspector requesting emergency repairs to a bridge by sending e-mail to the proper officials from a PDA. Also in this EMR paper, the different needs of small and large clinics are explored. They suggest a degree of freedom for the user to customize the system. This makes sense for our needs because each IDOT district is different and has it own set patterns.

In another article, the Massachusetts Highway Department (MHD) explored electronic inspections for bridges. This 1997 paper described a paperless inspection process that was on its way to being completed. At that time, MHD was reported to be satisfied with the process of changing from a system that is very similar to the process that IDOT's uses today to a paperless and high tech data collection system. This ambitious project included digitizing old data and making it available to the inspector. Also the plans called for MHD central in Boston to download and store all information collected and disseminate it to the regional districts. The information collected would consist of bridge data, video, photo, CAD drawings, and etc. PDA were again used to collect bridge information but only for PONTIS® information at this point. Also past bridge information was made available in the field to the inspectors (Leung 1997).

Nondestructive Testing Technologies for Condition Monitoring of Bridges

Cost effective maintenance and retrofit actions can only be effective if the authorities are properly warned in advance of impending degradation. The ideal nondestructive testing procedure for bridges will provide information about the existence and location as well as the extent of deterioration, corrosion or structural damage. At this point in time there is no one method that can provide this information. Most of the condition monitoring activities has been limited to visual inspections. A number of advanced nondestructive testing methodologies have been recently developed and currently being investigated by FHWA. These techniques were discussed in the proposal and they are referenced here for completeness. They include: **HERMES** Ground-Penetrating Radar System for imaging of delaminations in bridge decks; **Laser Bridge Deflection Measurement** system to measure bridge deflections up to a range of 30-meters; and **Stress-Measurement Technologies** for evaluation of load distribution and stress levels in load-carrying members. It is noted that some members of the bridge community remain skeptical about the value of ground penetrating radar.

In general, highway agencies have been conservative in adaptation of new NDE technologies. The technologies reported here pertain to those that have been adapted by various DOTs following many years of research and development. Ansari has compiled a complete review and presentation of both conventional, as well as unconventional NDE techniques for applications in civil structures in a series of books (Ansari 1992,1993,1997,1998,2000). A brief review of some of the more established technologies relevant to bridges will be described in the following paragraphs. This section will be followed by a review of smart bridges.

NDE of Bridges in North America

Sounding is the most commonly employed method for detecting internal cracks and delaminations in concrete. This method involves tapping the concrete with a hammer or dragging a heavy chain on the deck. The presence of cracks or delaminations is discerned by a characteristic hollow sound. ASTM D4580-03 provides the standard methodology for sounding. However, sounding does not fare well on asphalt-covered decks due to the inefficient coupling of energy between the asphalt and concrete. Therefore this technique is only used just prior to rehabilitation, for locating deteriorated areas after asphalt has been removed. Furthermore, the traffic noise adversely affects sounding's performance. Since sounding is a contact method, its use requires closure of traffic lanes, which is often costly and undesirable. The automated delamination device (Delamatect) was developed (Moore et al, l973) to remove all the operator judgments from the detection process. This is accomplished through operations with the recorded acoustic response of the bridge to an automated tapping stimulus. Independent tests by the Ministry of Transportation and Communication of Ontario (Manning et al, 1980) have indicated that the Delamatect is considerably less accurate than its manual counterpart. Canadian researchers report that Delamatect recognized only 67% of the delaminations found by manual sounding techniques. Other maintenance engineers have reported similar observations in regards to the Delamatect. Furthermore, employment of Delamatect requires intricate mapping and grid work operations.

Stress Wave propagation techniques, such as the impact echo method (Sansalone and Carino, 1989) have proven to be successful in locating cracks and delamination in concrete. However, these techniques require high levels of sophistication on the part of the operator. The method is based on the transmission characteristics of stress waves at the boundaries of different layers. For example, at a delamination, the reflection and refraction processes bring about changes to the energy of the transmitted stress wave, which can be picked up by a receiver. In practice, however, concrete is not a homogeneous material; there is considerable amount of noise in the return signal. Hence, the system requires sophisticated signal filtering and conditioning instrumentation. The echo methods show promise as they have successfully detected delaminations in field-testing of concrete decks. However, in regards to the application in asphalt-covered decks, they suffer from the same coupling limitations as in the sounding technique (Lee et al, 1990). Another disadvantage associated with the impact echo method is signal degradation in concrete containing more than few cracks. As stress waves pass through defects, they loose energy. Therefore, as the number of cracks and delaminations increase, it will be more difficult to predict their locations. These drawbacks have limited the practical usage of the impact echo method by the highway engineers (TRB report, 1991).

Infrared thermographic techniques locate subsurface anomalies by measuring the surface temperature under conditions of heat flow. Transient heating or cooling is required in order to produce the heat flow that results in the thermal gradient detection patterns. Highway authorities have taken advantage of solar radiation in driving the heat flow. Therefore, practical applications are restricted to sunny days, and favorable thermal conditions. Furthermore, infrared thermography is not capable of detecting the depth of the crack.

Ultrasonic pulse velocity method (ASTM C597-02) is relatively simple to use, and therefore, has been widely employed. This technique is not very effective in conjunction with small cracks. Furthermore, they often yield erroneous predictions as the pulse velocity will not significantly decrease when encountered by cracks filled with water or debris.

Pulsed radar techniques yield information on the structural profile across the depth of the object being tested. Existing research results indicate that on average, radar techniques are capable of detecting 80% of concrete cracks (Clemena, 1983). Results indicated that radar occasionally gave an indication of delamination in what was actually sound concrete. Further research is needed to increase the resolution of measurements as radar techniques do not resolve anomalies of less than a foot in width (Cantor and Kneeter, 1982, Clemena, 1983). Like experiences with GPR, some bridge engineers are concerned with the level of accuracy.

Laser-based roadway clearance measurement system was developed to solve the long-term problem of providing vertical clearance measurements along roadways (Mystkowski and Schulz, 1999). FHWA requires each state DOT to maintain an accurate record of these roadway clearances. Presently these measurements are made manually with telescoping rods. This requires a great deal of work because shutting down lanes is required and of course this creates congestion. Many employees are required for these tasks and potentially put at risk. The manual measuring of these clearances is reported by workers as one of the most potentially dangerous tasks to perform with speeding traffic close by. Also the accuracy of taking measurement under these conditions and with these crude tools is questionable. The Colorado Department of Transportation (CDOT) with the help of Bridge Diagnostic, Inc. developed a laser-based roadway clearance measurement system that is operated in a standard truck. The system consists of laser/ultrasound distance sensor, a signal processor, and laptop computer. The system works while the truck moves at 5 mph emitting the laser beam in the upward direction to the overhead obstruction. The beam is reflected off the unprepared surface. The laser is equipped to sense return signals these are fed to the signal processor that converts them to distance. Since it is very likely that bumps in the road could throw off the measurement a downward measurement is taken with an ultrasonic echo device. This measurement compensates for vertical movement in the truck so that readings are a true measurement of roadway to the vertical obstruction. The system can achieve accurate measurement to within half an inch of the actual.

The auto-sampling rate is high enough so that one pass can measure all girders. Some negatives do exist with the system. For instance the system should not be operated between the hours of 11 a.m. and 1 p.m. because the laser could be damaged. The best results occur actually later in the evening or at night. Environmental effects such as moisture in the air or cold weather also limit the system but not to the effect of the sun. Cost wise, the system has a high initial cost but a cost comparison study performed by CDOT showed savings of $275 per bridge for the automated system when compared to the cost of the manual measurement. These savings are mostly because fewer workers are required, 3 instead of 17, which more than offsets the initial cost of the system. Some other benefits are that the workers have been taken out of harms way and the information can easily be uploaded into a bridge management system.

The Strategic Highway Research Program (SHRP) conducted a survey (TRB report, 1991) that included interviews with bridge maintenance engineers of the transportation departments in all 50 states. The results of the survey indicated that visual inspections and chain dragging (sounding) were considered to be the most widely employed. According to these engineers, they could obtain the same or better degrees of predictability with sounding without the sophistication involved in using the more advanced technologies. For example, Ground Penetrating Radar (GPR) was criticized as having interpretation problems, and in many cases only 50% effective. As far as infrared thermography was concerned, it was cited as having mixed results, not doing the job well enough, too expensive, and not quite as accurate as chain drag. Ultrasonic testing was only employed in 11 states, and it was mainly performed in conjunction with steel bridges. This survey clearly indicated that current nondestructive techniques are cost ineffective, requiring bridge closure, unreliable, too sophisticated for the average bridge inspector, and in some instances, weather dependent.

Full scale tests

To date, only a few tests to failure have been conducted on full size bridge structures, and relatively few assessment tests have been conducted on full scale damaged structures. Rosli and Hofacker (1960) performed the first known test to failure on the Glatt bridge in Switzerland, a three span continuous, post tensioned concrete bridge. The AASHTO Road Test was conducted on eighteen large-scale test bridge structures, four of which tested to failure. These structures consisted of steel, prestressed and reinforced concrete elements. Burdette and Goodpasture (1970) performed what is believed to be the first failure tests of full size bridges in the United States. These tests were conducted in order to determine the ultimate capacity and the failure modes. Idriss and White (1991,1992) examined the effect of preimposed damage on the structural behavior and load carrying capacities of multi-girder bridge systems. The authors observed that when a defect is imposed in one of the girders, the concrete slab and the diaphragms in the vicinity of imposed damage redistribute the load to the adjacent girders. It was concluded that multi-girder systems possess a large amount of reserve strength in both damaged and undamaged configurations. Aktan et. al. (1993) tested a three span continuous reinforced concrete bridge to failure, and used system identification to identify damages present in the deck. Alampalli and Fu (1992) conducted modal tests on 1/6 th model of a steel bridge, and more than a dozen damage states were introduced. It was concluded that model analysis could only detect certain critical cracks in bridge structures. Idriss and White (1993) tested a three span continuous two girder fracture critical bridge, the I-40 bridge over the Rio Grande in Albuquerque. Several crack raisers were introduced in one of the main girders. The final failure occurred by way of a 6 ft. deep crack in the 10 ft. deep girder. Several nondestructive testing techniques were employed for locating the damaged zones.

Smart bridge systems and fiber optic sensors

Fiber optic sensors have been extensively employed as real-time damage detection tools in advanced aircraft and space vehicles. The increased use of advanced composites in aeronautics instigated the need for new damage detection techniques for monitoring the integrity of structural components while in service. External perturbations such as strain, pressure, or temperature variations induce changes in the phase, intensity, or the wavelength of light waves propagating through optical fibers. This change in one or more properties of light can then be related to the parameter being measured.

A number of European researchers and engineers have already employed optical fibers for detection of internal cracks in reinforced and prestressed concrete bridge systems (Wolff, 1990, Caussignac, et al, 1992). Others (Holst, et al, 1992, Rossi et al 1989, Fuhr, et. al., 1992, Mendez et al, 1989) employed optical fibers in reinforced concrete dams, large buildings, and tunnels. Wolff employed fiber optic sensors for monitoring of prestressing force, and crack formations in Schiessbergstrasse triple span (total span length of 53.0 meters) in Germany. For measurement of prestressing force, Wolff integrated four of the optical fiber sensors with the tendon during its fabrication. He further embedded four optical fibers on the top, and another four on the bottom portion of the slab, for monitoring the formation of cracks in the tension zone. Wolff reports crack detection capabilities with an accuracy of 0.15 mm. The Schiessbergstrasse bridge is part of an ongoing study for monitoring prestressing losses, and fiber optic sensor data is linked to the telecommunication fiber line via telephone hook-up. In a similar test-bed approach Caussignac, et. al. employed optical fibers for monitoring the bearing pressure distribution in the roller supports of a bridge with corroded elements. Unpublished activities in Canada (Transportation authorities in Calgary) indicate the use of Bragg grating type fibers and a manual switching technique for monitoring deformations and cracks in a two span reinforced concrete bridge.

All of these activities are geared towards full-scale integration of NDT in condition monitoring of structures. Expeditious conveyance of results to the practice of civil engineering requires test bed type research for verification and improvement of NDE technologies as they develop.

Monitoring and Damage Assessment

While a lot of research work has been done in the area of disaster prevention of large structural systems, very few methods have really been applied at field. The most frequently used technique for inspection is still based on visual methods, which are carried out at periodic intervals (~ 2 years for critical bridges). NDT of bridges such as Golden Gate Bridge would have to incorporate techniques that can identify local hot spots created by corrosion, overstressing, fatigue related cracking etc. In general large bridge systems incorporate large safety margins and are unlikely to collapse during their design life (unless there is a design problem such as Tacoma Narrows bridge in Washington). However a calamity in the form of a major earthquake (beyond the design specifications), a severe hurricane with very high winds, a sea going vessel ramming into the structure, or an act of terrorism, can result in a collapse of such a structure. While very few structures are instrumented to acquire data around the clock, some of the newer structures such as the Kishwaukee Bridge in Illinois has been instrumented with a wide variety of sensors

(Wang et al, 2000, Wang and Satpathi, 1997, Wang et al, 2000, Wang et al, 200b, Wang and Xu, 2000).

In order to develop a proper disaster prevention technology, effort has to be put into the following areas:

i) Monitor global structural response such as deformed shape, and other vibration characteristics.

ii) Detect change in the structural behavior or structural strength. This may include detection of change in stiffness, cracks in members, spalling of concrete decks and girders, corrosion in metallic structures, yielding and fracture of metallic components of a structure etc.

iii) Identify & monitor all the appropriate environmental quantities which interact with the structure such as traffic flow, traffic pattern and traffic loading; temperature cycles, wind directions and wind speeds, hydrological characteristics which might affect the soil structure or fluid structure interaction; and seismic events (Boothby and Laman, 1999, Kirmidjian and Basoz, 1997, Shanfelt and Horn, 1980, Sreenath, 1993).

iv) Develop appropriate models that will analyze all the necessary information and make a decision on the safety and reliability of a structure.

The key to the successful implementation of an on line monitoring system is dependent on:

i) Collection of appropriate data type (strain, acceleration, displacement, wind speed etc.). Ideally the collection of data should not interfere with the normal operation of the structure. It is also preferable that the monitored response is a result of the ambient environmental conditions.

ii) Developing a suitable model into which the data can be input and interpreted. The output of the system should be a quantitative assessment of the structures current health. This area is relatively under developed. While the technology for monitoring hot spots and making an assessment on a local scale is well developed, assessing the global reliability based on a global distribution of sensors is an elusive goal at the moment.

Thus a health monitoring system consists of a plethora of sensors typically arranged in an array. They monitor fatigue strain using various configurations of strain gauges; displacement sensors monitor peak displacement; accelerometers monitor dynamic response and mode shape; temperature sensors monitor temperature fluctuations; anemometers provide wind speeds; force measurement sensors measure cable forces; corrosion monitors monitor corrosion; and flow meters record hydrological data. However, one of the major problems associated with acquiring data from a large number of sensors is the physical process of wiring the sensors to their data acquisition system. In order to overcome this problem, the possibility of adapting wireless technology for data transfer is being explored.

While collecting the appropriate data represents one part of the challenge the other part of the challenge is posed by the problem of how to utilize this large amount of data to develop a suitable warning or collapse prevention system. While researchers unanimously agree that it is important to develop some type of a Finite Element base line model of the actual structure, there is not a whole lot of agreement on what techniques to use to make the actual predictions. For global monitoring a number of techniques, such as comparing the structural dynamic characteristics, have been suggested. The static influence line has been suggested in various literatures as a way of detecting a structural softening. They work only in a limited sense in terms of their damage detection capabilities (Lloyd and Wang, 2000, Lloyd and Wang, 1999, Miao and Wang, 1997). They have been able to detect damages of catastrophic magnitude in large bridges, but do not have the ability to detect the onset of a problem, since the damage has not reached a significant stage. Under the present circumstances it is probably appropriate to utilize a judicious combination of global and local monitoring system to put in place an effective health monitoring system. An ideal system should comprise of the following:

a) A good correlated finite element model of the structure to serve as the baseline. If a new structure is being considered as a candidate, appropriate measurements should be made to obtain both static and dynamic characteristics of the system and correlate the model with the actual test data.

b) Based on the finite element model, the probable hot spots should be identified. A health monitoring system based on local hot spot monitoring using strain gauge technology, acoustic emission and ultrasonic, force sensors etc. should be employed for hot spot monitoring. At the same time a global monitoring system based on measurement of acceleration response or displacement response be put together along with sensors for monitoring the necessary environmental parameters.

c) While the necessary models for global damage detection are not fully developed, a combination of current global damage detection techniques in conjunction with data from local structural monitoring sensors and environmental parameters collected from the appropriate sensors can be packaged together. Changes in the global damage detection parameters will have to be matched against data from localized sensors and environmental sensors. Discrepancies among the different sensor groups will have to be resolved initially by using expert bridge inspection engineers and will form the basis of developing an expert system to resolve conflicts between the different set of sensors, and eventually make assessments of safety and reliability of the structure. In the event of a situation where the expert system is unable to resolve a situation it will recommend an immediate detailed manual inspection, during which process new hot spots may be discovered and will have to be monitored. Also any time a change in the structure is detected and identified, it will be necessary to incorporate the changes in the Finite Element model.

d) If a scenario is deemed dangerous or has the potential of turning into a serious problem, appropriate retrofitting and repair should be undertaken.

Infrastructure Monitoring Technology group at the University of Illinois at Chicago is currently engaged in the following areas of research:

1) Design and development of self-contained wireless sensors. The idea is to develop a small battery powered unit that can provide the necessary excitation energy to the sensor element, do some basic processing to the signal and then transmit the data to a central data processing computer. From there the group wants to miniaturize the design for individual sensors.

2) Development of active sensors using PVDF films so that the sensors themselves require no external power for their operation. The group is actively working on developing dynamic strain gauges using PVDF films.

3) Around the clock monitoring of the dynamic characteristics of Kishwaukee bridge of 1100 ft using an Altus K2 recorder transmitter. The objective of this study is to characterize the modal parameter changes as a function of the temperature variation.

4) Instrument Kishwaukee bridge with a variety of strain sensors, accelerometers, etc. and carry out both static and dynamic experimental analysis of structures. Dynamic analysis capabilities include modal analysis using forced excitation and ambient excitation. Perform localized hot spot monitoring using conventional gauges. The system is capable of carrying out around the clock monitoring.

5) Appropriate Finite element model updating techniques for developing well correlated finite element model of actual structures.

6) Developing probabilistic neural network based damage detection expert system (Arockiasamy et al, 1993, Bollu, 1993, Brancaleoni et al, 1993, Chang, 2002, Elkourdy, 1993, Furuta et al, 1991, Hsu and Yeh, 1993).

B.3. Conclusion

There are a wide variety of technologies applicable to bridge inspection and management that are in various stages of development. As the technology is rapidly changing in this area, we must be careful to balance the capabilities with the availability of ongoing support. While several articles and promotional brochures proclaim the benefits of the technology, an historical overview suggests that there are few experiences with stable technology. It is also clear that the adoption of any new technology requires a comprehensive approach including training and planning for future upgrades. The literature also suggests that each application must be tailored to the needs of the particular agency.

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B.5. Annotated Bibliography

Barbash, Andrew, "Mobile Computing for Ambulatory Health Care: Points of Convergence" *Journal of Ambulatory Care Management,* 24(4); 554-66, October 2001. ☑

Ambulatory clinical environment is very similar to bridge inspection. A patient, much like a bridge, needs to have a sort of inspection done initially to determine the appropriate measures to bring the patient back to a favorable health. Similarity in bridge inspection this situation presents itself in the form of an inspection, mostly visual, to help to determine the rehab steps to bring the condition to an acceptable range. For both of these processes, although not required, old medical records or past bridge inspection reports can be a considerable help. This paper reviews how past electronic medical record (EMR) and tools have been taken to a new level with the addition of PDA devices and the expansion possibilities. It is a good idea to look in the broader sense and look outside civil engineering for potential resources. The paper begins by saying how past EMR system failed because of lack of effective tools for interacting with up-to-date clinical information in a mobile, personal, and practical manner. The solution to this problem seems to have come about with the availability of handheld devices with touch screens and some degree of handwriting recognition that increased the "knowledge" at the point of contact. This point of contact idea can be directly related to bridge inspection when the inspector finds himself in front of a flaw. It would be tremendously useful to have detailed rating information about the particular type of flaw available at the time the flaw is identified. Also several old inspection reports if they were available would help the inspector to make decisions about deterioration. Next the author goes into how this type of technology could lead to improved information sharing and request for work by easy synchronization. The author thinks that this approach could be used to lose the middleman in many medical transactions. It is easy to see how this could also be beneficial to IDOT. For example if a inspector comes across something he or she thinks needs some type of immediate repair he could mark it on his or her PDA and later when he or she connects to the larger system this information could be directly e-mailed to the proper officials. The author next goes into how a completely designed approach according to one branch's needs doesn't always fit the needs of another branch doing the exact same task. Maybe incorporating some user defined aspects into whatever potential product we suggest would be a good idea. He goes into this deeper by explaining the differences between the needs of small clinics and large clinics. "The structure, resources, functions, and relationships of large integrated group practices are substantially different from those of small independent community practices, and the differences have important consequences for the management of clinical information." I believe this is also true for IDOT. Its districts are different sizes and have different needs that we should be aware of and not design according to one district needs keeping a degree of functional customization for the separate districts.

Brito, Branco, Thoft-Christensen, Sorensen, An Expert System for concrete bridge management, Engineering Structures, Vol. 19, No 7, 1997. ☑

This selection explores a rational decision-making bridge management system mostly concerned with corrosion in concrete. The system is broken into two modules Bridge-1 and Bridge-2. Bridge-1 is to be used in a portable computer by the inspector at the bridge. The module provides the inspector with useful information about the bridge defects found before. Bridge-1 also is where new defects found are classified. To standardize this procedure a defect classification system was developed. When a defect is detected it needs to be selected from an extensive list of defects. After the defect type is selected a new window appears to classify the defect further such as causes of defect and etc. Bridge-2 is used at the office and handles the information from all the inspection in a bridge database. It uses several analysis tools to determine maintenance and repair strategies like economic and reliability analysis. Something that is interesting in this paper is they point out that most management system use a trigger method such as IDOT system of something dropping from a 3 to a 4 in rating to determine maintenance and repairs. The authors decided on a reliability-based system. The paper goes much further into bridge management and how exactly Bridge-2 works to optimize maintenance and repairs. The paper is well written and easy to understand specifically addressing the structure of this system.

Chajes, Michael J., Harry W Shenton III, Dennis O'Shea, Use of Field Testing in Delaware's Bridge Management System, TRB Transportation Research Circular 498, 1999. ☑

This paper is an introduction to field-testing of bridge and the different projects the University of Delaware has conducted that centered on field-testing for the Delaware Department of Transportation. Field-testing in the sense it is used in this paper is the actual putting the bridge into specific loading conditions and observing and collecting data. This data is then used for the primary reason of determining the load rating of the bridge. The testing has impact on the bridge management by giving an accurate load capacity. This, if not done, might give the impression that the bridge might be structurally deficient, which would cause money to be spent where they are not needed. Basically the field-testing gives a condition rating on a specific behavior of load capacity and this rating is then later used in the management.

Chase, S. and G. Washer, "Nondestructive Evaluation for Bridge Management in the Next Century," *Public Roads*, Vol. 61 No. 1, July/August 1997. ☑

This paper provides a catalog of the all the NDE methods that FHWA NDE research program is currently testing. Giving a brief description mostly non-technical of the NDE item and its potential uses. This paper describes many of these system, some involving optics, others involving acoustic emission. It only addresses the NDE bridge management integration briefly in the beginning for about three paragraphs. Even though the second objective of the FHWA NDE research program is "to develop technologies for the quantitative assessment of the condition of bridges in support of bridge management and to investigate how best to incorporate quantitative condition information into bridge management systems." The authors briefly go into the fact that this NDE information is far more reliable then visual inspection. What the authors do not say about the issue of integration of the NDE tools into bridge management is as follows. Data from the field is sent to a large database were it is analyzed. Then multiple lists of management options are made that are prioritized according to need that the analyzed data suggest. These lists are made up of what projects need to be started with the funding, resource, and future predicted deterioration all taken into account. The authors then tell us that these systems have had tremendous success but give no specific examples.

Elzarka, Hazem M., "Automated Data Acquisition For Bridge Inspection," *Journal of Bridge Engineering,* November 1999. ☑

The author of this paper worked along side with South Carolina Department of Transportation (SCDOT) in an automation process of their bridge inspection procedures. Specifically the paper focuses on a pen-based bridge inspection system developed for the SCDOT. The author briefly discusses the old paper form process and inventory database. This database contains record information on the type of elements in a highway bridge and their associated condition. The quality of the database is reliant on accurate information of the inspection process being transferred. The author's point in describing this process is because of the large amount of data collected and that automation will not only bring the data in a more timely manner to the database but it will also be more accurate. The manual data entry process is time consuming and is prone to errors. With a Personal Digital Assistance (PDA) the inspection form can be digitized and the data retrieved, updated, and stored quickly and more accurately. One of the advantages to the pen based system to the authors is the entry of data in several different ways. For instance pointing to menu selections, scrolling down data lists or options, and writing characters on the screen.

The system that they investigated was Automated Bridge Inspection System (ABIS). It was developed using the Padbase Software Development Kit. Some of the capabilities that are included in this system are the ability to select options from scrollable lists, make handwritten entries, and store field sketches. The author tells us that the application on PDA was relatively simple to learn in a two-day training session. The ABIS development effort required 5 man-months, which included designing the forms, defining the databases, developing the code, and compiling the executable file. The inspector has the option of placing flag modules contain data referencing bridge conditions that require immediate attention. These conditions are classified as either ''structural'' and/or ''safety.'' The author believes in not overwhelming the inspector with technology. That is why pen-based computers were chosen as they replicate existing paper forms. "It is important to note, however, that when automating the bridge inspection process, one should select a data acquisition system that does not differ substantially from the current paper-based system to gain acceptance." The designer of the system kept in mind the physical condition of the bridge inspection environment, text and graphics were chosen in a way that is easy to follow and view on the relatively low-contrast LCD and where poor lighting conditions exist. Of course also prior to a field inspection, data from previous inspections are available on the system.

Garrett, Jr., J. H., A. Smailagic, S. McNeil, R. Hartle and P. Kane, "The Potential for Wearable Computers to Support Bridge Inspectors in the Field," Proceedings of the TRB Annual Meeting, January 1998, Washington D. C. ☑

This article mostly discusses the potential for wearable computers to support bridge inspectors in the field as they inspect the individual elements of bridge and record their findings. The paper starts with the overview of the bridge inspection process and the current approaches to computer support for bridge inspectors, which tells us why an wearable computer are in need in field inspections. Two previous applications are briefly described. Then the paper goes into the potential for using wearable computers to support bridge inspection. Two recent models, the VuMan3 for support of maintenance of amphibious vehicles and Navigator2 for maintenance of KC-135 Aircraft, are introduced to readers on the aspects of their purpose, design, usability, and cost controlling. Different from the above two example, bridge inspection require the computer system to support information from each bridge to be collected and entered into in advance so that they can be accessed on site. Meanwhile, bridge inspection requires a user-centered design on the wearable computer interface. Some recommendations on the improvement of current wearable computers are based on feedback from bridge inspectors. Those recommendations are very critical on how the wearable computer to development to satisfy the requirement of the field inspection. Finally, the author summarizes the potential impact of using wearable computers for bridge inspection. That is reducing cost, providing accuracy inspection, and improving the quality of data access.

Hartle, Raymond A., Mary P. Rosick, and Harold C. Rogers, Jr., "PennDOT Bridge Inspection Data Collection E-Forms" International Bridge Conference, Pittsburgh PA, June 2001.

PennDOT's E-Forms are electronic versions of the Department's standard Inspection Form: Series D-450. The software product developed by Michael Baker, Jr., Inc. enables bridge inspectors to electronically record and update bridge inspection field data on-site. Using standard Microsoft Access database software, the product also generates hard copy reports and automatically links directly to PennDOT's mainframe database. The link to the mainframe allows for automatic download. One of main advantages that the technology provides is to eliminate data re-entry. PennDOT envisions an approximate timesaving of 15-20 minutes per bridge. The E-Forms followed the logical sequence to inspection. This type of organized data collection gives more reliability so that no bridge elements are overlooked. E-forms have safeguards built into it so that old bridge data is not accidentally copied over. No records are allowed to be copied or deleted to protect the integrity of the database.

Hearn, G. and Shim, H., "Integration of Bridge Management Systems and Nondestructive Evaluations," *Journal of Infrastructure Systems*, Vol. 5 No. 2, June 1998.

NDE methods used in bridge inspection offer data that support definite, but narrow determinations of some attributes of elements, materials, or deterioration processes. This paper mostly presents works in progress on the direction use of data from nondestructive evaluation methods in bridge management systems.

Bridge management systems seek to optimize maintenance and repair programs with information on repair needs, costs and rates of accretion of new needs. Qualitative condition ratings are used in the United States as the result of bridge inspections. NDE and BMS are integrated by defining condition ratings in a form that admits determination or detection by NDE methods.

The new integrated condition states are defined as stages in service life of bridge elements. There are four attributes: exposure, vulnerability, attack and damage. These attributes produce five condition states: protected, exposed, vulnerable, attacked and damaged. At the same time, thresholds for interpretation of NDE data are adjusted for consistent assignment of condition states. The condition states are mutually exclusive and detectable. They correspond to repair or maintenance actions and indicate severity, but not extent, of damage. The author propose that, as condition ratings represent mechanisms for including both qualitative and quantitative data, have common definitions, and an ordinal scale, they can be adapted to account for NDE data as opposed to modifying the BMS to account for additional data. Using this approach, NDE methods determine condition states for bridge elements by detecting or measuring attributes of states. The level of criticality of the structure or structural element determines when the structure needs to be analyzed. Analysis tools are used to perform analysis so that to ensure the safety of the structure. This renders the concepts of safety inspection and rating data in BMS essential to the need of performing analysis.

Hearn, George, “NDE in Bridge Management Systems,” *Transportation Research Circular* 498, 8th, April1999. ☑

This paper by Hearn addresses most thoroughly that problem of bringing non-destructive evaluations (NDE) methods for the use of bridge management systems. Hearn includes NDE data by interpreting it as condition ratings. The definition of condition state is a judgment of a bridge component condition in comparison to its original as-built condition. Thresholds are applied to the raw NDE data in a way that they mark the barriers to different condition states that will be later plug into the bridge management system such as PONTIS®. Hearn develops the concept in this paper that there are four types of NDE test that can be performed for protection, vulnerability, attack, and tests for damage for an element. Examples of this system are given in the paper. Data from NDE tests would be interpreted as condition ratings. This provides the basic link between the NDE field-testing and BMS like PONTIS®. This method would require the user to define the thresholds for NDE test data. After these thresholds have been defined condition states could be assigned to tested areas. Some probability calculations need to be done. Two aspects, variability in measurements and uncertainty in the meaning of measurement, need to be considered, together with the impact of changes of properties and service ages. Modifications are made to minimize errors. The interpretation of test data provides the basic link between bridge testing and bridge management, so that we can use the test data to calibrate models of deterioration. Although this paper does not describe the data interpretation procedure in detail, it does give us a general idea on how to integrate test data for bridge management system.

Leung, Albert, Sanjiv Nathwani, and Avanti Shroff, **“**Implementation of Total Electronic Inspections for Bridges”**,** International Bridge Conference, Pittsburgh, PA, June 1997.

This paper was prepared for the International Bridge Conference in Pittsburgh in June of 1997. Two who wrote the paper were in private industry they helped the Massachusetts Highway Department (MHD) develop an electronic inspection system. The other author was a employee of MHD. The company that the two private industry authors work for were Trilon and Iffland Kavanagh Waterbury. The authors presented this paper at a point were the electronic inspection had not fully developed at conference time. The research was on its way to being completed it would be interesting to see how it developed beyond this point. Anyway at the time of the conference some satisfaction had been reported from changing a system very similar to IDOT's today into a paperless and high tech data collection system. They ambitiously wanted to digitize the old data and make it available to the inspector. The designers wanted MHD central in Boston to download and store all information collected. They would also be responsible to disseminate the data collected over a computer network to the regional districts for their use. The information collected would consist of bridge data, video, photo, CAD drawings, and etc. PDA were used to collect bridge information but only for PONTIS® information at this point. Also past bridge information was made available in the field to the inspectors.

Phares, Brent M., Dennis D. Rolander, Benjamin A. Graybeal and Glenn A. Washer, " Studying the Reliability of Bridge Inspection," *Public Roads*, November/December 2000.

This paper is written as a brief introduction on how the visual inspection (VI) reliability study initiated at the Federal Highway Administration's Nondestructive Evaluation Validation Center (NDEVC) was conducted. The goal of the study was to provide an overall measure of the reliability and accuracy of routine and in-depth inspections and to study the influence of human and environmental factors on inspection reliability. Two important components of the study, state-of-the-practice survey and field investigation, are described by the authors but not in detail. Based on the survey, the authors point out the that VI is the most common NDE method used in bridge inspection but professional engineers are typically not in the onsite inspection team. No conclusion of study is given. Field investigation was done by 49 inspectors, representing 25 states. According to the authors, information about the inspector and inspection environment was collected to assess their influence on inspection reliability and monitored by NDEVC for conclusion. Next, the paper goes into describing the study on impact factors on the reliability of bridge inspection – the human and environmental factors. Inspectors were asked to complete the bridge inspections and provide condition ratings of bridge elements and documentation. Compared with the environmental factors, the human factor is more difficult to measure. So questionnaires were given to all participating inspectors in two phases, three direct physical measurements were made concerning the possible influence VI reliability, and each inspector's activities and behavior are documented. The authors strongly support that the study will help define the accuracy of normal bridge inspection. But since no detail results and conclusions are included, readers cannot be convinced.

Phares, Brent, Dennis D. Rolander, Benjamin A. Graybeal, and Glenn A. Washer, "Reliability of Visual Bridge Inspection", Public Roads, March/April 2001 ☑

This article is the second of two reports on the visual inspection study conducted at NDEVC. Different from the last one, this article mostly focuses on describing the result of the study. The conclusion is based on the collection of inspection results and assessment of visual inspection reliability influenced by the inspectors' performance. Results of both routine inspection and in-depth inspections are summarized by the author, followed by analysis of example bridge inspections. In routine inspections, there are great variability in element-level inspection results, inspection notes, and photographs taken by different inspectors, especially in condition rating. In in-depth inspection part, the author points out that the inspection may not yield any findings beyond those that could be noted during a routine inspection when an in-depth inspection is prescribed. The deck-delamination survey is conducted during this investigation but results are showed to not be consistently accurate. The authors suggest that as the predominant tool used to assess bridge conditions, visual inspection need significant improvement, but no definite solutions are given.

Roberts, James and Richard Shepard, "Bridge Management for the 21st Century," *Transportation Research Record 1696.* 2000.

This paper mostly addresses some new bridge maintenance applications such as health index (HI) and Virtis in California.

Firstly, the authors point out that good design, strict quality control and quality assurance, and timely and thorough maintenance inspection are the principle bridge maintenance philosophies. However, because of government strategies, high-cost consuming programs, such as rehabilitation and replacement are adopted rather than the lower cost maintenance programs. Over the past 10 years, more and more research has been done in this area, and new bridge management programs have been developed. The concept of an optimal maintenance strategy means performing small projects at the right time to avoid the cost of larger rehabilitation and replacements.

Then, the authors introduce a newly developed performance measure referred to as the health index (HI), for the structural condition of a single bridge or a group of bridges. The HI uses element inspection data to determine the remaining asset value of a bridge or network of bridges. It is the ratio of the current element value to the initial element value of all elements on the bridge. The current application of HI in California has proven effective in helping understand the overall condition of a bridge or network of bridges, such as to allocate resources, to judge district bridge maintenance and rehabilitation performance, and to aid in the evaluation of annual budget strategies and life-cycle performance. Examples of budget allocation and condition prediction using HI are given.

The final part of this article is a brief introduction to Virtis, a part of the bridge engineering software named BRIDGEW, used to incorporate the new load and resistance factor rating (LRFR) specification. Installation of Virtis can provide many benefits for bridge analysis such as rapid emergency response, safe and efficient movement of permit traffic, determination of bridge damage costs due to truck traffic and compatibility with bridge design.

Small, Edgar P., Terry Philbin, Michael Fraher and George Romack, "The Current Status of Bridge Management System Implementation in the United States," Denver, Colorado, 1999. Transportation Research Circular 498, "Presentations from the 8th International Bridge Management Conference.☑

This paper mostly addresses the current practices of the state DOT in Bridge management Systems (BMS). It gives a nice description of BMS as "BMS is intended to provide decision support throughout the transportation planning process and within the project planning, development and implementation stages of bridge programs." The paper begins with the historical need of BMS sighting famous bridge failure and the creation of the National Bridge Inventory. The author spoke of the lack of a clear decision making methods of deciding what to bridges to fix. Next the reader is told how PONTIS® and Bridget BMS software were created. The two different programs are contrasted. The author points out that BRIDGET was a bottom up approach while PONTIS® was a top down approach. Both systems have a clear purpose to “maximize safety and minimize the life-cycle costs.” PONTIS® is more widely accepted among the state DOT. No reason was given why. Next the paper goes into describing the survey that was performed. The form of this part is a questions asked to the DOT is written then a summary of the responses from the state DOT follows. Some items of interest in this part are the Quantitative vs. Qualitative goals. Also some states use the BMS system to help them plan their State Transportation Improvement Programs STIP. Next of interest is question about electronic data collection and NDE systems integration. No states had a completely paper free system. Only one state claimed to have a successful inspection data collection system. In term of NDE systems only basic system such as dye penetration were used widely. One state used advanced system for special situations. Other states had specialized NDE teams that inspected. Still no clear answer was given if the data produced was being transferred into the BMS systems.

Sunkpho, J., J. H. Garrett, Jr., and A. Smailagic, "Opportunities for Speech Recognition for Bridge Inspection," Proceedings of the 2000 ASCE Construction Congress, Orlando, FL, Feb 20-22, 2000. ☑

The authors of this paper were specifically evaluating speech recognition as a potential hands free inspection process. The idea behind hands free inspection is that this would allow the bridge inspector to have full range of movements given him/her more freedom to inspect thoroughly. The Authors of this paper often compared speech recognition with personal digital assistants (PDAs). The authors of this paper also give some background information of speech recognition systems. The IBM Viavoice™ system was used to collect speech and convert spoken word into text. One of the flaws that the authors saw with this system was that a greater amount of error occurs when using the speech interface when compared with the PDA. This was a result of the software confusing words spoken with other that it converted to text. The major benefit was that this system was a time saver when compared with the personal digital assistants almost cutting in half the time to perform a task. They made these evaluations by having a group of three students in Civil Engineering Department to run through on mock laboratory inspection. The size of sample of only three students is suspect. Also, the fact that they had students in a laboratory and not inspectors in the field makes the conclusion questionable. The authors also point out these weaknesses in the conclusion.

Washer, Glenn A,. “Developing NDE Technologies for Infrastructure Assessment,” Public Roads. January/February, 2000.☑

This paper is written to inform the interested public about the FHWA a Nondestructive Evaluation Validation Center (NDEVC). The center was set up in order for the FHWA to evaluate different non-destructive techniques. The need produced itself for this center because few NDE technologies have been widely implemented as part of routine inspection procedures. FHWA sees NDE technologies having a large impact the bridge inventory in two important ways. By detecting deterioration in its early stages, new technologies can help ensure the safety of highway bridges. Second, these technologies can assist in the management of the bridge system by accurately determining maintenance and repair requirements. So this independent lab provides state highway agencies with independent evaluation and validation of NDE technologies, develops new NDE technologies, and provides technical assistance to states exploring the use of these advanced technologies. The center comprises three elements: the NDE laboratories; component specimens, which are sections of bridges containing defects; and field-test bridges. The Center has five decommissioned highway bridges and components specimens to provide realistic testing platforms. They have tested and help develop HERMES a Ground-Penetrating Radar System that can reliably detect, quantify, and image delaminations in bridge decks. Also NDEVC has helped to develop a Laser Bridge-Deflection Measurements, which has helped load-rating bridges experimentally, a process that can be expensive and time-consuming. The development of new NDE technologies for the inspection of highways and highway bridges will assist FHWA in attaining its strategic goals by helping to effectively manage the highway system in the 21st century.

APPENDIX C.

COVER LETTERS AND SURVEYS

This appendix contains the surveys used to gather information from IDOT and other state DOT's as summarized in Table 9.

Table 9. Surveys Used

Survey	Administered	Number Distributed/ Requested	No of Responses
IDOT practices	Telephone Interviews	5 bridge maintenance engineers	5
		15 bridge inspectors	13
	Field Interviews	5 districts	5
	Office Interviews	2 locations	2
Other states practices	Email	52 states	27
Follow up	Telephone interviews	15 states	15
Field Visit	Interviews	4 states	4 s

C.1. Questions Used for IDOT Telephone Surveys

1) What position do you hold in IDOT? (District Engineer, District Bridge Maintenance Engineer, Bridge Inspector, or Data Entry Individual)

2) How long have you worked at this position?

Questions about bridge inspection process:

3) Were you trained before starting your position? (FHWA, IDOT specific training) What did it involve and how long did it last?

4) Briefly describe how you perform a bridge inspection process? (inspector)

5) How does the process differ when you encounter different types of bridges, surrounding environment, bridge conditions, or other factors? (inspector)

6) What is the most inconvenient part of the process?

7) Can you identify unusual circumstances that involve data collection not in the normal inspection cycle? (e.g. construction, damage, accident)

8) Beside visual inspection, what kind of technology do you use in the field? Are they helpful in the inspection process?

9) What could make the inspection process easier?

10) How do you check the reliability of the data collected by inspectors at your district? (bridge maintenance engineer).

11) How do you check the reliability of the data you collected? Do you compare to old inspection reports of that bridge. (General for inspector).

12) Do you have any advice on how to improve the field inspection process?

Questions about bridge maintenance and decision making: (Bridge Engineers, Bridge Maintenance Engineers)

13) Briefly describe how you use the data collected from the field?

14) What approach do you use to make decisions on maintenance?

15) What other information could be helpful in the decision making that you do not normally have access to, because lack of availability or that the information is not collected?

16) How do you interact with IDOT Central office/district offices? When do you feel it is necessary to interact with them? (District/Central)

17) What could make the decision making process easier?

18) What databases do you use in the decision making process currently? Is there an analysis tool that produces reports that would help in the process?

19) What version of Pontis are you using? Do you find it useful? Is the bridge program influenced by Pontis reports / information? If so, how does Pontis influence your program? If not, could it have any affection in the future?

Questions about data entry

20) How do you record the data in the field? (Inspector)

21) Describe the data entry process in the office? (General) Who does it?

22) How many different databases does the data entry individual have to enter information into? Is there ever the case where he has to enter a particular field twice? Does the information stay just in one database after it has been entered?

23) How long after the inspection is the data entered into the databases of IDOT? How long after can it be used?

24) What part of the process is most likely to involve errors in data recording or entry? (Bridge maintenance engineer, Bridge engineer)

25) How can you find an existing inventory error?

26) Who is responsible to correct these errors? What is the process and what is the protocol/chain of command to get it done?

27) What information that is collected in the inspection process is not included in the existing databases?

28) What can make data entry easier and free of errors?

29) Question about data entry technology:

30) In terms of visual inspection aids, have you ever used hand held devices or wearable computers in your inspection process? Are you interesting in these aids?

31) Have you ever used visual capturing devices such as cameras in your inspection process as an aid of visual inspection?

32) What do you feel are the advantages of these aids?

33) If you use the Newton Apple, who was responsible to test the accuracy of the collected data?

34) Are there any specific electronic inspection forms or other software for these handheld devices that you have ever used?

35) Are you interested in further development of a handheld device inspection form?

36) Did you ever receive any training involving these systems specifically training for the Newton Apple?

Question about NDE technology in field testing

37) How much do you know about NDT/NDE?

38) Which kind of NDE technology have you ever used in bridge inspection? Which techniques do you use regularly?

39) How do you integrate NDE data into IDOT databases and programming?

40) Which NDE technologies are you interested in?

41) Are you interested in developing a NDE inspection form?

42) Should the depth of our project be considered with

- Pre-inspection procedure (Management)?
- Inspection procedure (Visual inspection aids)?

- Post inspection (Management)?
- Other?

43) Anything else?

C.2. Cover Letter to Other State DOTs

Illinois Department of Transportation

2300 South Dirksen Parkway / Springfield, Illinois / 62764

November 25, 2002

Mr. Earle S. Freedman
Deputy Chief Engineer
Bridge Development
Maryland State Highway Administration
707 North Calvert Street
Baltimore, Maryland 21202

Dear Earle:

In conjunction with the University of Illinois at Chicago (UIC), through the Illinois Transportation Research Center, the Illinois Department of Transportation is exploring recent advances in non-destructive evaluation (NDE) technology and new technologies for field data acquisition and storage for bridge inspection. The objective is not only to provide new and better data, but to improve the process. Like other states, maintaining, repairing and rehabilitating Illinois' more than 8,000 bridges in a cost effective manner is critically dependent on reliable inspection and condition assessment data.

We have surveyed each of the 50 state Departments of Transportation and have made follow up phone calls to states that use NDE technology or that have experiences of interest and relevance to Illinois. Maryland has been identified as a state of interest. The researchers at UIC will be contacting you and your staff to schedule a visit to your office.

The purpose of the visit is to obtain first hand information on Maryland's approach to bridge inspection and how it relates to bridge management. We anticipate the visit to take two (2) half-days including, if possible, a field visit with a bridge inspector.

The researchers have been communicating with
Joseph Miller, Chief, Bridge Inspection and Remedial Engineering
410-545-8311, Email: Jmiller5@sha.state.md.us
If you would like to designate someone else on your staff as a point of contact,

please contact the principal investigator at UIC:

Professor Sue McNeil
Urban Transportation Center
University of Illinois at Chicago (M/C 357)
412 S. Peoria St, Suite 340
Chicago IL 60607
Telephone - 312-996-9818
Fax - 312-413-0006
Email - mcneil@uic.edu

We will be happy to share the summary of our visit with you and your staff. Of course, if you have any concerns, please do not hesitate to contact me or Sue McNeil. We hope that our research will be of benefit to everyone and thank you in advance for your participation.

Very truly yours,

Ralph E. Anderson
State Bridge Engineer
Illinois Department of Transportation
2300 South Dirksen Parkway
Springfield, IL 62764
217-782-2124
andersonre@nt.dot.state.il.us

C.3. Questionnaire to Other State DOTs

Bridge Inspection and Assessment - Questionnaire to State DOTs

Please complete the following questions. This questionnaire should take less than 15 minutes to complete:

1) What types of routine inspection is undertaken in your state (check all that apply)?

___ NBI

___ PONTISÒ

___ Bridget

___ State specific

___ Other. Please specify ____________________________

2) Who conducts inspections (check all that apply)?

Routine	Indepth	
___	___	DOT employees
___	___	Contractors/ Consultants
___	___	Other, please specify ___________________________

3) What is the typical time in the field spent inspecting a standard 2 lane, 3 span bridge over a creek (check one)?

___ Less than 1 hr

___ 1-4 hours

___ 4-8 hours

4) Is data entry done in the field or the office?

___Field

___Office

5) What is the typical time required for data entry and reporting for a standard 2 lane, 3 span bridge over a creek (check one)?

___ Less than 1 hr

___ 1-4 hours

___ 4-8 hours

6) How many inspectors are there in your state? _______

7) How many bridge are these inspectors responsible for? _______

8) How many people are on a typical inspection team?

___ 1

___ 2

___ 3

___ Other

9) What are the qualifications of inspectors in your state? Please indicate your estimate of the percentage in each category:

___ Professional Engineer

___ Graduate Civil Engineer

___ 2 week training course with 5 years experience

___ 2 week training course

___ none

___ other

10) Which databases are used in your state?

___ PONTIS® with Cybase

___ PONTIS® with Oracle

___ NBI

___ Other, please specify ________________________________

11) Which bridge management systems are used in your state?

___ PONTIS

___ Bridget

___ None

___ Other, please specify ____

12) What devices are used for field data collection (please check all that apply)?

Occasionally	Regularly	
___	___	Clipboard and forms
___	___	Personal Digit Assistant (PDA)
___	___	Wearable computer
___	___	Electronic clipboard,
___	___	Tape recorder,
___	___	Voice recognition,
___	___	Laptops,
___	___	Other (Please specify) __________________________

13) Which non-destructive testing technologies do you use (please check all that apply)?

Occasionally	Regularly	
___	___	Ground penetrating radar
___	___	Infrared thermography
___	___	Ultrasonics
___	___	Stress wave propagation (impact echo, dynamic loading)
___	___	Fiber optic sensors
___	___	Other (Please specify) __________________________

14) Does your state undertake Large Scale Monitoring of bridges?

___ Yes - Number of Bridges _____

___ No

15) Does your state undertake Remote Monitoring of bridges?

___ Yes - Number of Bridges _____

___ No

16) Do you have any ongoing research on bridge inspection, data collection or data management?

___ No

___ Yes - Please specify ____

Contact Information

Name: ______________________________________ Title: _____________________

State: ______________________________Telephone Number: _____________________

Email: ________________________ Please check if you would like a summary of all the responses ____

Return Information - Please Email (lippertdl@nt.dot.state.il.us) or Fax (217/782-2572) your responses to David Lippert at Illinois Department of Transportation

C.4. *Follow up Question for Other States*

Illinois Transportation Research Center

ITRC Project IVD-H1, FY 00/01

Evaluation of Bridge Inspection and Assessment in Illinois

Follow Up Questions for Other States

STATES USING LAPTOPS/HANDHELDS

STATE:_____________

DATE: _____________

1) How are you using the laptops/ handhelds in the field?
2) Describe the system?
3) How does the laptop / handheld interface with other systems? (mainframe, database, PONTIS®, as appropriate)
4) How long have you been using it?
5) How widely is the system implemented (geographically and by whom)?
6) How widely is the system used (geographically and by whom)?
7) Describe the development process?
8) What kind of training do you have, how frequently is it offered, what is the duration, who provides it?
9) Do you use specialized hardware? If so are there specific models or configurations? Is there anything you would not recommend?
10) Describe your software?
11) Do you customized or off the shelf software?
12) Do you consider the system reliable?
13) How do you maintain and upgrade the system?
14) Do you have any written or electronic material?

C.5. ***Questions for Field Visits to Maryland, Montana, New York and Pennsylvania***
Illinois Transportation Research Center

ITRC Project IVD-H1, FY 00/01

Evaluation of Bridge Inspection and Assessment in Illinois

FIELD VISITS: QUESTIONS FOR STATES

Information to obtain in advance of the visit:

- Organizational chart (overall organization, bridge section/division, field offices)
- Inspection forms and manuals
- Any documentation on tools and technology

These questions are grouped in four areas:

- Initial contact Person – overall process
- Bridge Management Specialist/ Data Management Specialist/ Bridge Maintenance Engineer – bridge management, data and decision making
- Bridge Inspector – field experiences
- Specialized questions by state

Initial Contact Person (Background Information)

1. What position do you hold? What is your role?
2. How long have you worked at this position?
3. Outline the process for bridge inspection and data entry include a description of any technology that is used?
4. Describe bridge management process in your state?

5. Describe data management process in your state including the databases used to store inventory and condition data related to bridges and information related to decision-making?

Bridge Management Specialist/ Data Management Specialist/ Bridge Maintenance Engineer

1) What position do you hold? What is your role?
2) How long have you worked at this position?
3) Questions about bridge inspection.
   a) How is bridge inspection organized?
   b) Who reviews the data collected by the bridge inspectors?
   c) Do you have any advice on how to improve the field inspection process?
4) What information is in the typical bridge inspection file? Is it possible to get a copy (both paper and electronic) of this information for a typical 3-span bridge?
5) Questions about bridge maintenance and decision making:
   a) Briefly describe how you use the data collected from the field?
   b) What approach do you use to make decisions on maintenance?
   c) What could make the decision making process easier?
   d) What databases do you use in the decision making process currently? Is there an analysis tool that produces reports that helps in the process?
   e) What other information could be helpful in the decision making that you do not normally have access to, because lack of availability or that the information is not collected?
   f) How do field offices interact with central office?

g) Do you find your bridge management system useful? Is the bridge program influenced by reports / information?

6) Questions about data entry

   a) How is the data recorded in the field?

   b) Describe the data entry process? Who does it?

   c) Who reviews the data?

   d) How long after the inspection is the data entered into the databases? How long after can it be used?

   e) What part of the process is most likely to involve errors in data recording or entry?

   f) What information that is collected in the inspection process is not included in the existing databases?

   g) What can make data entry easier and free of errors?

7) Question about data entry technology (where appropriate tailor to the specific state):

   a) Do you use hand held devices or wearable computers in your inspection process?

   b) Do you use visual capturing devices, such as cameras, in your inspection process as an aid of visual inspection?

   c) What do you feel are the advantages of these aids?

   d) If you have not used any device, skip to the next question, otherwise:

      i) What training did you receive?

      ii) Are there any specific electronic inspection forms or other software for these handheld devices that you have ever used?

8) Question about NDE technology in field testing

a) Which kind of NDE technology have you ever used in bridge inspection and how extensively?

b) How do you integrate NDE data into IDOT databases and programming?

Bridge Inspector:

1) What position do you hold? What is your role?

2) How long have you worked at this position?

3) Questions about bridge inspection process:

    a) Were you trained before starting your position? (FHWA, IDOT specific training) What did it involve and how long did it last?

    b) What information do you take with you into the field?

    c) Briefly describe how you perform a bridge inspection process?

    d) How does the process differ when you encounter different types of bridges, surrounding environment, bridge conditions, or other factors?

    e) What is the most inconvenient part of the process?

    f) Can you identify unusual circumstances that involve data collection not in the normal inspection cycle? (e.g. construction, damage, accident)

    g) Beside visual inspection, what kind of technology do you use in the field? Are they helpful in the inspection process?

    h) What could make the inspection process easier?

    i) Who reviews the data you collect? Do you compare it to old inspection reports of that bridge?

    j) Do you have any advice on how to improve the field inspection process?

4) Questions about data entry

    a) How is the data recorded in the field?

    b) Describe the data entry process? Who does it?

c) How long after the inspection is the data entered into the databases? How long after can it be used?

d) What information that is collected in the inspection process is not included in the existing databases?

e) What can make data entry easier and free of errors?

5) Do you keep a hard copy of the bridge inspection? If so, for how long.

6) Question about data entry technology (tailor to specific states):

a) Do you use hand held devices or wearable computers in your inspection process?

b) Do you use visual capturing devices, such as cameras, in your inspection process as an aid of visual inspection?

c) What do you feel are the advantages of these aids?

d) If you have not used any device, skip to the next question, otherwise:

e) What training did you receive?

f) Are there any specific electronic inspection forms or other software for these handheld devices that you have ever used?

7) Question about NDE technology in field testing

a) Which kind of NDE technology have you ever used in bridge inspection and how extensively?

8) How are critical deficiencies handled once they are identified?

Specialized Questions

New York: Software developer

Briefly describe the integrated data management system.

Who initiated the project?

How did the project evolve?

How will the system be maintained, updated, enhanced?

Strengths?

Weaknesses?

Words of advice?

Montana: Information technology person

Briefly describe the web-based bridge management system.

Who initiated the project?

How did the project evolve?

How will the system be maintained, updated, enhanced?

Strengths?

Weaknesses?

Words of advice?

Pennsylvania: Project manager

Briefly describe the use of wearable computers/ PDA's for bridge inspection and data entry.

Who initiated the project?

How did the project evolve?

How will the system be maintained, updated, enhanced?

Strengths?

Weaknesses?

Words of advice?

Florida/Maryland: Project Manager

Briefly describe the system for including images in the bridge inventory database.

How are the data accessed and archived?

Do you provide guidance on resolution and quantity of images?

How are the images managed? Who has access to the images?

APPENDIX D.

IDOT PRACTICES

D.1. Introduction

Understanding the needs of IDOT personnel is critical to the success of this project. Both field and office personnel have concerns, issues and needs. Task 2 of the project identified these elements. One-on-one meetings, field visits and telephone interviews were used to explore the needs of IDOT with respect to bridge inspection and assessment. In summary, the report draws on:

- Visits to Districts 1, 2, 3 and 8 including field inspections
- Telephone interviews with all district bridge maintenance engineers.
- Telephone interviews with 15 bridge inspectors
- Participation in inspection of I-55 Bridge across Des Plaines River.
- Meetings with Central Office BMS personnel
- Review of reports

This working paper documents the findings of this part of the project and recommends specific directions that the project should take in response to these findings. The report is organized as follows. The follow section provides on overview of the IDOT structure and describes how we approached this part of the research. The next section reviews the field visits and the following section summarizes the results from the telephone interviews. The remaining sections describe opportunities for improvement and presents conclusions.

D.2. Overall Structure of Bridge Inspection and Assessment in IDOT and the Approach to Data Collection

IDOT is organized around a central office in Springfield and nine districts. Under the Division of Highways, the Bureau of Bridges and Structures is separate to the districts. The Bureau of Bridges and Structures is organized around four sections:

44) Services Development

45) Design

46) Bridge Planning

47) Structural Services

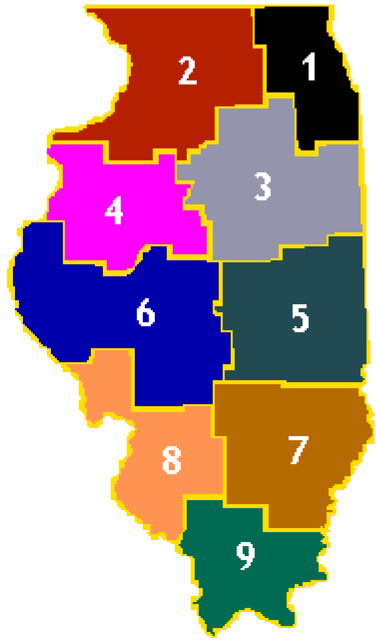

Figure 20. IDOT Districts

All sections except for design are involved in this project.

The Services Development Section includes the bridge inspection unit. This unit is responsible for inspection of all the major river crossing and some specialized and fracture critical bridges. The Bridge Planning Sector and Structural Services Sector have support roles in this context.

The nine districts are shown in Figure 20. Each district is responsible for the inspection and maintenance of the bridges in their district.

Table 10 shows the number of bridges and bridge inspectors in each district. The District Bridge Maintenance Engineer in the Bureau of Operations in each district is responsible for bridge inspection and assessment. IDOT uses a variety of databases and computer tools.

D.3. Bridge Management and Databases at IDOT

A variety of Bridge Management tools and databases are used at IDOT. Those relevant to this study are summarized in Table 11. The relationships among the various tools are shown in

Figure 21. This section provides an historical overview of how these various tools and databases evolved and how they are used.

Table 10: Bridges and Bridge Inspectors in Each District

District	Number of Bridges	Number of Full time Inspectors
1	1469	23
2	1000+	5
3	875	4
4	600	3
5	875	4
6	970	4
7	734	4
8	900+	6
9	630	2

In response to the ISTEA mandates for bridge inspection, IDOT initiated a study to review existing bridge management practices and explore the feasibility of implementing a comprehensive bridge management system. The study was conducted by Cambridge Systematics (Cambridge Systematics 1993 and 1994). IDOT began using PONTIS® in the mid-1990's. Districts complete the PONTIS® inspections but rarely use the data for decisions making.

PONTIS® is a PC based bridge management system. Version 2.0 was originally installed in the districts and it has only been during the course of this project that Version 4.0, a Windows based version, has been installed. Some districts reporting have problems with hardware that was unable to run the new version, and very few district personnel had had any training on how to use PONTIS®.

In recognition of the variety of tools and databases a study was undertaken by the BMS Joint Application Development Team that documented the various tools and databases. The study charted the relationships between various tools and databases and provided much of the data for Table 11. The study also resulted in the development of SIMS as a tool to provide easy access to a variety of bridge related data. The motivation for SIMS is described as follows:

To make the bridge data more accessible and useable to its engineers and inspectors, the Department has developed a database application utilizing Microsoft Access® that contains the ISIS data. This application is called "SIMS", or "Structures Information Management System".

Source: http://www.dot.state.il.us/sims/sims.html (Date accessed: June 29, 2002)

The use of the tools for decision-making and analysis is poorly documented with the exception of BAMS. BAMS is a prescriptive tool for developing the five-year bridge program and the annual program. BAMS is the implementation of a well-defined set of rules that produces a list of bridges in each of four categories (Backlog Critical, Other Backlog, Accruing Backlog and Long-Term Backlog). The criteria and categories are defined in Table 12.

Table 11. Bridge Management Tools and Databases.

Name	Ownership/ Access	Language	Bridge Data	Links From…	Links To…
AASHTOWare PONTIS®	Districts, Bureau of Bridges and Structures, and Office of Planning and Programming (OP&P)	Links to Sybase database	Inventory, NBI data, PONTIS® elements and ratings	ISIS	SIMS
AASHTOWare Virtis/Opis®	Bureau of Bridges and Structures	MS SQL/ACCESS	Bridge Rating and Design data		ISIS (manual)
BAMS - Bridge Analysis and Monitoring System	OP&P	EZTrieve+	Compares structures against set criteria	ISIS	PPS
BARS - Bridge Analysis and Rating System [1]	Bureau of Bridges and Structures	Fortran	Load rating and permitting	-	ISIS (manual)
BPT – Bridge Project Tracking	Bureau of Bridges and Structures	Nomad	Bridge Planning, Design, and Repair Project data	PCS, ISIS	SIMS
BPT – Bridge Project Tracking (New)	Bureau of Bridges and Structures	Microsoft SQL/ACCESS		PPS, ISIS	SIMS
Element Level Inspection Database	Bureau of Bridges and Structures	Microsoft SQL/ACCESS	Element Level Inspection data	PONTIS®	SIMS
IRIS - Illinois Roadway Information System	OP&P	IMS/COBOL	Traffic and highway data	-	ISIS
ISIS - Illinois Structures Information System	OP&P	COBOL	Inventory, NBI data	IRIS and MMI BARS (Manual)	PONTIS® etc
MMI - Maintenance Management	Bureau of Operations	COBOL	Bridge inspection data, maintenance	ISIS	ISIS

Information System [2]			data and cost data		
PCS – Pre-Construction Status System	Districts, Bureau of Bridges and Structures, and OP&P	Nomad	Improvement projects	PPS	BPT, SIMS
PPS – Planning and Programming System	OP&P	COBOL MS SQL/ACCESS	Categorization	BAMS	SIMS, BPT, PCS
Repairs	Bureau of Bridges and Structures	Microsoft SQL/ACCESS	Bridge Repair and Maintenance Project data	ISIS	SIMS
SIMS - Structure Information Management System	Bureau of Bridges and Structures, and OP&P	Microsoft SQL/ACCESS	Inventory, NBI data	ISIS, BPT, Repairs, PONTIS®, PPS, PCS	

[1] BARS is “sunsetting,” IDOT is moving to Virtis®

[2] Bridge data being removed from MMI

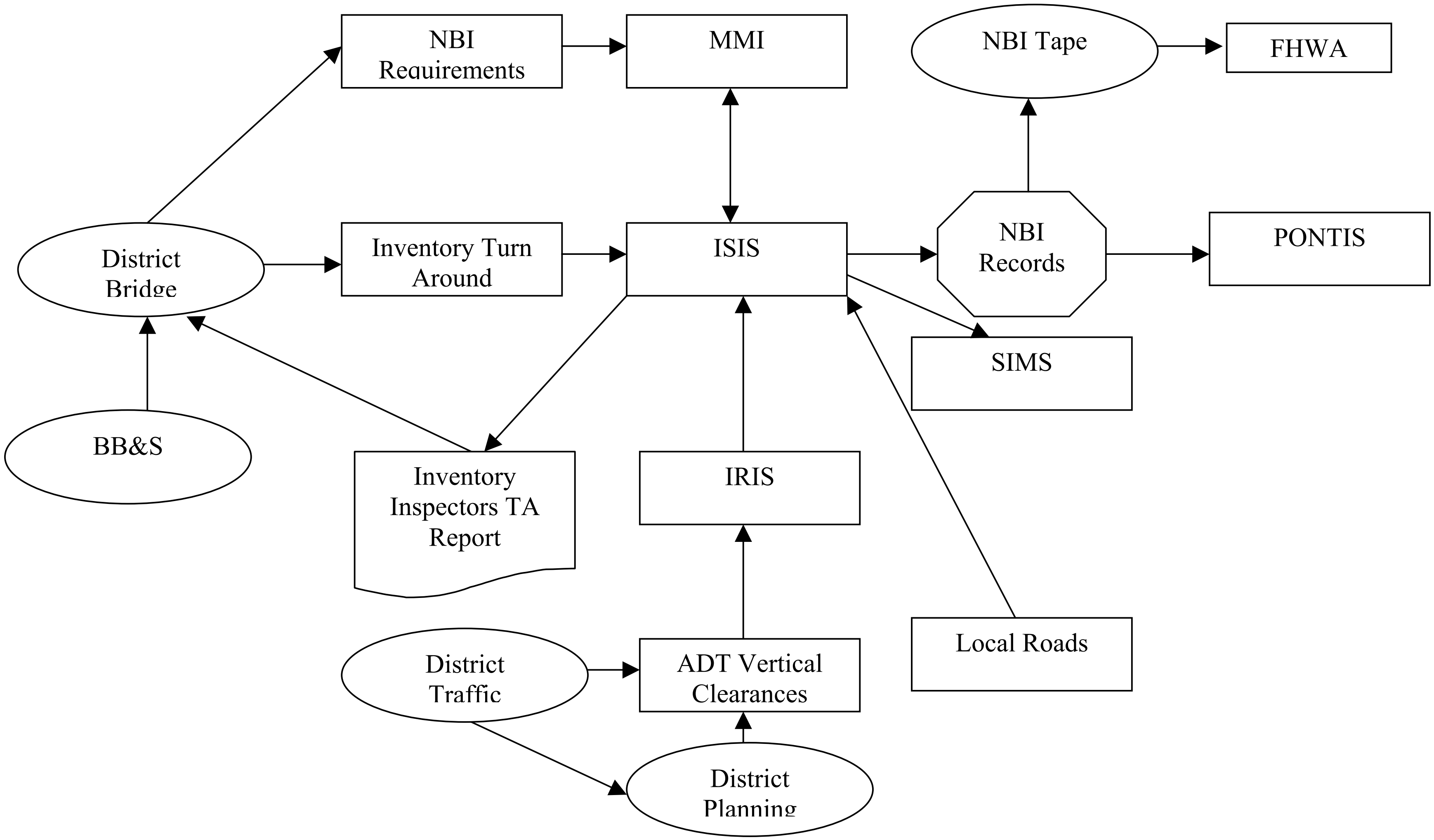

Figure 21. Software and Databases for Bridge Management

Table 12. Criteria for Determination of Illinois' Bridge Needs

State-Maintained Structures (Planning or Original Logic)					
SD * or FO	TABLE #	WHEN: ITEM NUMBER	DESCRIPTION	RATES: RATING	THEN: NEEDS CATE-GORY
SD	1	59, 60 OR 62	Super, Sub or Culvert	0 - 3	Backlog Critical
SD	2	58	Deck	0 - 3	
SD	3	67	Structural Evaluation	0 - 2	
SD	4	70 A2, B2, C2, D2	Posted Load Limit	D2 > 0 or A2, B2, C2 Not Spaces	
SD	5	59, 60 OR 62	Super, Sub or Culvert	4	Other Backlog
SD	6	64 A & B	Operating Rating	0 - 26 Tons	
FO	7	68	Deck Geometry	0 - 3	
		29/ON	AADT/ON	≥ 1000	
FO	8	69 **	Under clearance	0 - 3	
		42B	Type of Service Under	1, 2, 4, 6-9	
FO	9	72	Approach Alignment	0 – 3	
		29/ON	AADT	≥ 1000 ON	
SD	10	58	Deck Condition	4	Accuring Backlog
SD	11	67	Structural Evaluation	3	
SD	12	59, 60 OR 62	Super, Sub or Culvert	5	
SD	13	64 A & B	Operating Rating	27-35 Tons	
FO	14	130	Sufficiency Rating	0.0-49.9	
FO	15	29/ON	AADT ON	≥ 1000 ON	Accruing Long Term
		51	Bridge Roadway Width	1.0-23.9	
			-OR-		
		29/ON	AADT ON	1-999 ON	
		68	Deck Geometry	0 - 3	
FO	16	130	Sufficiency Rating	50.0-80.0	
*SD: Structurally Deficient FO: Functionally Obsolete					

D.4. Examples of Field Inspection Practices

In order to evaluate bridge inspection and assessment it is necessary for one to go out in to the field and actually observe the practices of IDOT employees. Over the first couple of months of the project our team was able to go and visit multiple sites. We visited central crew first as they were inspecting a fracture critical bridge where I-55 crosses the Des Plaines River.

We also took trips to districts one, two, three, and eight. Summaries of each of these field visits are included in an attachment.

This review is not meant to be a detailed description of all five trips but rather what we came away with from the combined observations. The first thing that was obvious from these field visits is that the needs and the practices of IDOT districts vary considerably among districts. The bridge inspection process although essentially a centrally taught and planned process for all districts has evolved differently in each district. For instance the central inspection crew is primarily involved in high-level detailed inspection of significant or troublesome bridges. While some of the more rural districts visited do not spend a significant amount of time in high level inspection but more generally spend their time involved in routine inspection. These differences in practices of course transfer to different needs of the central crew compared with a more rural district. The effect of this is that the central crew has more use for NDT techniques while the rural districts are more reliant on visual inspection. Another key difference noticed between the districts is that some are more urban than other districts. Although this is a seemingly a trivial difference, it does have an effect on bridge inspection. Urban environments have more traffic, giving rise to greater fatigue in the bridge causing fracture critical elements to be more of a concern. More salt is often used in these environments causing corrosion to be more of an issue. Both of these concerns produce a type of inspection that documents specifics like crack length and section loss rigorously.

The extent of the use of part time seasonal inspectors varied greatly between the districts. Some of the districts visited did not use any seasonal inspectors. Other districts greatly relied on these workers to inspect the bridges. Up to 8 inspectors work seasonally in some of these districts. This difference has some implications on our proposals to improve the inspection process. For instance, if we decide to propose an electronic inspection report the number of units available to perform such an inspection could become an issue. It would not seem prudent to have some inspectors using a new electronic system and another set of inspectors in the same district using the old paper forms. This could possibly lead to errors in reporting between inspectors. Also training could be an issue for these seasonal inspectors, finding the right time for IDOT to train as many people as possible in order to be cost effective could prove difficult.

In the district some similarities did present themselves. The most noticeable of these was that they all continually refereed to the IDOT manuals for NBI rating descriptions and the PONTIS® coding book for coding numbers and condition descriptions. The problem is that they were all seemingly using different versions. It should be looked into to make sure that the most recent version of these manuals is being used.

In general, among the inspectors there was an animosity towards electronic inspection technology. They viewed it as ineffective as if they were being replaced. The Newton Apple experience is generally considered to be a disaster because of multiple problems with the device. Although most inspectors said they would be willing to try anything. Many of these negative experiences can be traced back to a lack of training or clear purpose for the device. Essentially paper was still necessary with the Newton, which confused the purpose of the project.

The seriousness with which the collection of PONTIS® data is approached varied between districts. From our brief visits it seemed as though some district centered their entire inspection process around PONTIS® claiming that they performed an element level inspection. It seemed as though some other inspectors in different districts viewed PONTIS® as a chore, as it was essentially useless and placed less significance on that part of the inspection.

Of course, not all time was spent in the field at these districts. An overview of the activities at the office was also reviewed. In the office the databases were all the same for the NBIS inspection data with inspectors using the MMI system. The PONTIS® database did vary though, some were using an antiquated database that did not run on windows and others were using a Microsoft Access based database. One thing did seem obvious to us as we visited the different districts; the PONTIS® data was definitely underused at the district level. The data and software were not effectively being used compared to it proposed purpose when PONTIS® was first introduced. Most decision-making was made off of NBIS triggers such as when a rating dropped to a four then an investigation and proposed remedy was thought out.

From these visits our research group has learned that significant differences are present among the districts. Also that whatever suggestion we make for improvement of the inspection process should keep these differences in mind. Knowing the needs of these districts helps us with the brainstorming of ideas for that reason these trips were invaluable. The next step was the interview process that will give us even more insight on these matters.

D.5. Summary of Practices

Background

To obtain a comprehensive picture of the processes used for bridge inspection, data collection, and data, how the data is used and issues related to monitoring and inspecting bridges, we conducted a telephone survey of district bridge maintenance engineers and bridge inspectors. A representative sample of 23 individuals was from all 9 districts and central bridge crew were interviewed. Using a predefined set of questions we interviewed the bridge maintenance engineer in each district and where possible two bridge inspectors in each district over the telephone. We did not interview the temporary help inspectors. The questions used for the interview are included in Appendix C. A consent form that was approved by the University of Illinois at Chicago (UIC) Institutional Review Board (IRB) was used. All interviews were voluntary. The interviewees had freedom to skip any questions they preferred not to answer or have no knowledge of.

Each interview took around 30 minutes and data was recorded as notes. The following section summarizes the responses. The summary responses are organized as follows. Each question is identified and the response outlined. Comments from the research team are included in italics.

In total with interviewed (either via telephone or in the field) 10 District Bridge Maintenance Engineers and 13 Bridge Inspection Technicians.

The average period of the interview personnel holding their position is 7 years. The distribution is shown in Table 13. The responses are presented in the categories used in the interview questionnaire.

Comment: The respondents as a group are experienced bridge inspectors.

Questions about the bridge inspection process:

a) Training received

Table 14 summarizes the responses to the question about the about of training received.

Table 13. Experience of Respondents

Years in Position	Number of Respondents
Above 20 years:	1
10 – 20 years:	6
3 – 10 years:	7
1 – 3 years:	8
Under 1 year:	1

Table 14. Training Received

Training	Number of Respondents
NBIS (Baker Engineering)	18
Fracture critical bridge inspection	14
PONTIS®	7
Respirator training	1
Bridge painting IDOT course	1
Univ. of Wisconsin courses	1
Movable bridges	1
NDE	4
Confined space inspection	3
Under water inspection	1

b) Briefly describe the inspection process:

The core of the inspection process across all districts is fundamentally the same. This consist the scheduling the inspection, reviewing the materials relate to the structure, inspecting the structure, rating the structure, and recording of the data.

The details of the inspection process vary with the structures and from inspector to inspector. Many of these differences are a result of different approaches in the individual districts. For example a minority of inspectors do not review NBIS values or PONTIS®

quantities before they start the inspection. The theory here is that they believe reviewing before hand will skew their results by influencing them to look for particular flaws and not having a fresh approach to the structure. Other inspectors like to review the notes on the NBIS form from previous reports before inspecting in order to know the problem areas of the structure. By doing this, they feel more prepared to thoroughly inspect the bridge. Some inspectors bring a set of 11” by 17” plans of the bridge to the site or review entire plans at office to have idea of the components of the bridge and what they need to inspect.

In the field the inspector puts out appropriate traffic control devices. Most prevalent inspection approaches for the IDOT employees are a top down or a bottom up approach. This just simply refers to where they begin their inspection. Some start at the deck while others start at substructure. One inspector uses a voice-recording device when he inspects to take verbal notes instead of written ones, which are the norm. Many inspectors reported that they made sketches of various individual sections of the bridges documenting defects. It was reported that they try to inspect in two person teams. Most inspectors will have a clipboard and forms, and will also carry a hammer and a thickness gauge.

The majorities of inspectors return to their vehicles and begin to rate the bridge by reviewing notes taken in the field. Inspector might write additional notes in the NBIS form documenting new findings or continuing a previous history. All changes are recorded in the written report.

> *Comment: While each district produces the same basic information, the process used to collect the information, record and enter the information differs from district to district. The interviews supported what we found during the field visits.*

c) How does the process differ when you encounter different types of bridges, surrounding environment, bridge conditions, or other factors?

Every bridge is unique. One inspector said in their district each bridge has a sheet named “Bridge Inspection Documentation Sheet” that includes traffic control information or any specialized tools needed.

d) The most inconvenient part of the process:

The most inconvenient part of bridge inspection process is traffic control problem. Inspectors find it is difficult for them to decide how much traffic control they will need and find out where is the best place for them to park. The accessibility to the actual structure to ensure detailed inspection is another problem. Either design that means not all parts are visible or facility's configuration prevents access to a particular part of the bridge is another big problem. Other issues such as carrying the PONTIS® coding and rating condition booklet, the detail explanation for NBIS, and the ability of rating and estimation quantity are mentioned by individual inspectors.

e) Procedure of identifying unusual circumstances that involve data collection other than normal inspection:

Generally, by checking ratings of the structures, bridge maintenance engineers take care of those bridges in their district with rating of 4 or lower. The BME will receive a phone call if anything out of the ordinary has happened to the bridge. They will then go to the site to observe, determine immediate response. The information collected at this time is fed to a bridge accident report form and then filed with the other bridge files. However, details of what they do are case by case. The repair unit of each district will handle the short term or immediate problems.

f) Technology used besides visual inspection and their effects:

Not many technologies are used as auxiliary for visual inspection. The digital cameras/35mm cameras are most widely used by each district and received very good reputation. Some inspectors say that they use calipers to measure thickness and felt it is helpful. Some districts use NDE technology for the same purpose. However, the assessment of effectiveness of NDE varied from district to district. One felt the Sonar is helpful in underwater survey, another thought the report from these technologies can by inaccurate so they don't use them.

g) What could make the inspection process easier?

One of the responses to this question was each individual inspector develop their own style over time. For instance, some like to review the NBIS ratings before the inspections and others like to review afterwards. These stylistic differences hold for during the inspection process too. While some inspectors like to use many tools to help with the rating of the bridge, others prefer to heavily rely on visual inspection. Some of those interviewed believe these differences make it hard to make any suggestions to improve or ease inspection process.

Another main suggestion among mostly district bridge maintenance engineers was to review Ground Penetration Radar Technology in deck patching inspection. Some of the district BME's reported positive experiences while others reported that the projected quantities of a bridge deck patching were completely off the mark. They felt if the data was reliable it could be a very useful tool.

The BME's would like to see the new bridges designed for IDOT to be friendly to the inspectors. This meaning that the bridge allows for close visual inspection for as much as the bridge as possible. Also that traffic control procedures be optimized.

A few of those interviewed expressed their interests of development the electronic data collection system that could avoid entering the data twice into the paper form and database form.

h) How does BME check the reliability of data collected?

In general, NBIS still serve as the primary information source and database for bridge inspection. Comprehensive report review for the quality control purpose is done by BME. For a particular bridge of rated below 5 or lower or having a significant downgraded rating, BME will have his or her attention drawn to these structures. Normally, a repeated inspection to warrant the grade is done by the BME (or together with inspectors) when necessary.

Comment: Respondents focused on verification of ratings when ratings fall below a critical threshold. They did not address the situation rated a bridge highly when in fact it should be rated at a lower value.

i) How do inspectors check the reliability of data collected:

Inspectors check the reliability of their inspection quality by reviewing the previous bridge ratings and reports. However, the procedures are different among them. Some inspectors like to read the previous reports before doing their inspection to know the expecting result; some inspectors never do this before they finish their own report to avoid influence. The supervisor will check the data and initial the report and BME will review all inspections and take care of the specific structure with significant lowered ratings.

Comment: Districts that use teams of two or more inspectors have a built in mechanism for checking.

j) Any advice on improving the field inspection process:

Two major categories of advice are given.

The first category is about the data collection device, they suggest using laptops, which is also used for data entry in the office. Voice recording devices and PDAs are also suggested as the helpful devices in the field for data collection.

Second, the inspection form needs to be improved.

Some inspector complained that certain fields did not exist in order to properly rate bridges. One considered there no place to rate a slab bridge properly. Others complained about the deck part of the inspection form for the NBIS as you cannot distinguish the rating for the top versus the underside.

Questions about bridge maintenance and decision making: (Bridge Engineers, Bridge Maintenance Engineers)

a) How is the data collected from the field used:

Programming individuals rely heavily on BME’s input, especially for specific bridges. NBI ratings are used most frequently to flag and identify a problem. Most engineers state that PONTIS® information is seldom used except some districts after they have flagged deficient structures with NBIS information then use PONTIS® data to get a closer look of actual conditions. Most express their interests in using the PONTIS® information more.

b) What approach do you use to make decisions on maintenance?

Generally, through inspection process, databases are filled then reports are created. Reports are run by the specific ratings of certain elements. In terms of programming, a top down approach using 16 tables is produced by the programming engineer. Detailed information is added by the BME using a more bottom up approach. Majority of decisions are still relied on the obvious problems of bridges been identified with some evidence. MMI/SIMS is used to extract information, but seems not very effective for decision-making. Budget is another important issue for decision making.

c) Other information that could be helpful:

1) Up to date programming information.

2) Digital versions of photos, memos and sketches.

3) Plans and files that cannot be carried to the field right now.

4) Effectively used PONTIS® information

d) The interaction between IDOT Central Office and District Office:

The interactions between IDOT Central Office and District Office are varied from district to district. Some districts have a good amount of contact while others have the minimum amount. Generally speaking, there are good interactions with central bridge office, poor with central operations sections that the BMEs report to. Interactions are made by emails and phone calls for the purpose of decision-making. The central Office provides policy help and expertise in bridge engineering.

e) What could make the decision making process easier:

The only suggestion is to share SIMS queries between BME's.

f) Database used in the decision making process currently:

MMI-NBIS

This database contains almost everything of the past inspection and is used sometimes to obtain information on a specific structure. Some inspectors feel the data is not very user friendly. There is insufficient room for remarks.

SIMS

This database is not used for data entry but for queries. It is used extensively for decision-making, bridge project tracking, programming information event though it is out dated programming information. However, some operations do not have SIMS.

ISIS – works with program development

IRIS – Not every district have these two databases.

GIS and PONTIS® – Some district use them occasionally, while others never use them.

Comment: The fact that the BME and inspectors interact with many databases is an issue in itself. The fact that several of these databases also require specialized computing skills (e.g. SQL) adds to the complexity.

g) What version of PONTIS® are you currently working with:

The most current version of PONTIS® in IDOT is version 4. This version is either in a start-up stage or not implemented yet because of hardware issues in some districts. The old version of PONTIS® is seldom used except for entry and quantity readings. Most though expressed this old version as useless.

Comment: In the current set up at the time of the interviews, it was very difficult to use PONTIS® data for decisions.

Questions about data entry

a) How does bridge inspectors record the data in the field?

Paper forms and pens are the most general methods used by inspectors. The central inspection team has a prepared field book with them. The norm for the district inspector was the use of a clipboard for any notes. Others use voice recording.

b) The general data entry process in the office:

The inspection personnel fill most of the collected data in the databases. Although some district have chosen one individual to fill in PONTIS® data for the entire district. The NBI data is put into MMI database. PONTIS® ratings are recorded in the office into PONTIS® Access databases. If any ratings are lower than 4 (or 5 in some districts or the grade is significantly lowered), the report will be reviewed by the supervisor.

c) Types of different databases that data entry individual has to enter information into:

There are two basic databases. One is MMI for NBI data; the other is an access database for PONTIS® ratings.

d) How long after the inspection is the data entered into the databases of IDOT? How long after can it be used?

The period of entering the data after inspection changes depending on the district. The shortest duration is a day or two while the longest duration is about 30 days. Generally, the average period of the data entry is one to three weeks after the inspection is completed.

e) The part of process that is most likely to involve errors in data recording or entry:

Majority of BME's express that data entry is a process that most likely to involve data recording error. The limited access to items for visual inspection is another cause for those inaccurate data among inspectors. Other inspectors think the monotonous nature of the work could lead to mistakes being made. Some BME's feel the initial problems existing in the databases and understanding the new SI procedure manual may be the causes.

f) How can bridge individuals find an existing inventory error?

There seems no effective method in inventory error finding procedure. The experience of the data entry individuals and reviewing individuals are very important. If the problem is related to status, it is changed immediately. Mistake in inventory are backlogged. Inspectors find them and generate lists. *(is it the generate one?)*

g) Who is responsible to correct these errors? What is the process and what is the protocol/chain of command to get it done:

The planning and programming section is responsible to correct the error in inventory. If there is any errors in the inventory sheet, inspectors will check in the field, change any error in red ink , then take the errors to the supervisor. Memos need to be made. In other cases some inspectors are allowed to change these errors in some fields

h) What information that is collected in the inspection process is not included in the existing databases?

The following items are addressed by the interviewers for the missed information by the existing databases:

- NBI notes except that the rating for the structure is low.
- The table of all the documented deficiencies.
- Photos of flaws.
- Deck planks.

i) What can make data entry easier and free of errors?

Update the existing MMI database that record NBI data.

Develop a data entry system that may enter the inspection data only once.

Use verbal recording device to make the inspection and data entry more convenient.

Improve the ability and experience of inspectors by job training.

Questions about data entry technology:

a) Hand held devices or wearable computers used in inspection process:

A minority of the inspectors responded that they had never used any handheld devices or wearable computers during their inspection process before either because they were not employed as a bridge inspector or they were not handling the device in their office. Some of those who did use the Newton said that they did not like it because of its poor performance and the environment conditions on site. On the other hand a few expressed that their work benefited from Newton because of its ability of reducing the amount of paper forms in field.

Even though some had negative experiences with the Newton most expressed their willingness on the idea of using hand held device or wearable computers (such as palms) in the field. They felt that the general idea of paperless inspection was a good one if the bugs were worked out. Some put in their wish list for these devices to be hand free and be able to access plans. Only a few inspectors said he had no interest in the further development.

b) Any visual capturing devices such as cameras as an aid of visual inspection used in the inspection process?

Both digital cameras and 35mm cameras are used to document the damage of structures. Some districts mainly use digital cameras regularly to electronically record and transfer report. Some districts mostly use 35mm cameras as visual capture device due to the limitation number of devices available to them.

c) The advantages of these aids:

For the digital cameras (and other visual capture devices), the first advantage is that they make the interaction with central office speedy and accurate. Second, the district office can set up a visual document electronically, which make the documentation process easier.

d) Who was responsible to test the accuracy of the collected data:

For those districts that use Newton Apple, not everyone is respond to check the accuracy of the collected data. Only few individual will do this work (mostly not the inspectors themselves). Persons who have ever used this device addressed the disadvantages of it. The biggest one is the problem with download. The form of Newton did not match the forms of IDOT and the device cannot be used well in the harsh environment conditions such as rain, cold, and sunshine will disable the use of Newton too.

e) Any specific electronic inspection forms or other software for these handheld devices:

Some inspectors shared that to get rid of the paper and clipboard completely impossible.

f) Are you interested in further development of a handheld device inspection form:

The seventeen responses are shown in Table 15. Some inspectors would like to see the development of the new handheld device but they want the new device to address the problems they experienced with the Newtons and the devices need to be easily handled.

Table 15. Interest in Handheld Devices

Category	Number of persons	Percentage
1. Interested	7	41%
2. Conditionally interested	6	35%
3. Not very interested	2	12%
4. Doesn't matter	2	12%

g) Any training involving these systems specifically training for the Newton Apple:

Some did receive training, which was one day where someone from central office came down and showed them the download process and the data entry in the office. This consisted of one day and was not reported by all that used the Newton.

Questions about NDE technology in field testing:

a) How much do you know about NDT/NDE:

The knowledge of NDE/NDT of the bridge people is taken mostly through training courses and the previous experience before getting this position. Some districts do not use the NDE/NDT very often. The technology is basically used when it is needed, especially on the exploration for fracture critical structures.

The most often used NDE/NDT technologies are ultrasonic, Magnetic particle and Dye penetrant. Others technologies, such as chain dragging, GPR, pin hanger flaw detector and thermography, were also mentioned by some respondents.

b) Which kind of NDE technology have you ever used in bridge inspection? Which techniques do you use regularly? (Summary from 14 responses)

Table 16 summarizes the results of this question in terms of the percentage of responding states that use a particular technology, and then of those states using the frequency of use expressed as a percentage of "often", "not often" and "not at all."

c) How do you integrate NDE data into IDOT databases and programming:

Some district will record part of NDE data into NBI-MMI database or FC form. Some have specific sheets for the data taken by some particular technologies. These sheets or forms in the office are mainly for personal uses. Some districts do not integrate the NDE data into their databases, but only use them for rating at site or back in office.

The inspection forms may be downloaded from the web:

http://www.dot.state.il.us/bridges/bridgforms.html (Accessed 6/30/02)

Table 16. Use of Non-Destructive Testing

Technology	Percent Used	Frequency of Use		
		Often	Not Often	Not at all
Dye Penetrant	52%	35%	17%	48%
Mag particle	57%	39%	17%	43%
Thickness gauge	26%	13%	13%	74%
UT	61%	43%	17%	39%
GPR	17%	17%	0%	83%
Chain Drag	13%	9%	4%	87%
Sonar	4%	4%	0%	96%
Hammer	13%	4%	9%	87%
Rebar Detector	9%	9%	0%	91%
No NDE	17%			
No. of interview	23			

d) Which NDE technologies are you interested in:

The specific NDE technologies which some were interested were GPR, Laser device and broader use of ultrasonic devices.

e) Are you interested in developing a NDE inspection form:

It seems there nearly no interests on developing a NDE inspection form. People feel the existing form or binder is enough for personal use.

Anything else:

About bridge inspection:

- Use large memory for damage capturing.
- Snooper problems.
- Site control problems due to traffic.
- Welds in 3-girder system need to be properly checked.

About maintenance and decision-making:

- Bridge databases need to be more responsive to districts. For example, easily updating data, correcting errors and more controllable by the bridge maintenance people.
- More sharing of information among district.
- Have an integrated system to simplify the data entry and transfer.
- Explore Cartograph's Bridge Management System as a way to organize the data and decision-making.
- Lots of information in the current database, which are not friendly.

About data entry:

- Use laptop as data input device (on site or in the office). Or find a efficient device on site to shorten the time of inspection.
- Need a seamless process to duplicate the paper files.

Others:

- Inspection individuals need additional knowledge, updated technology and need continuing education.
- Environment and facilities in the office.
- Issues regarding inspection vehicles.

Summary

The inspection process varies by district. However, the overall process is focused on producing the same results, specifically NBI inspection data and PONTIS® inspection data. Table 17 summarizes basic information about each district. The table is not intended for comparisons of the districts but to illustrate the similarities.

Figure 22 also summarizes the basic process. It is interesting to note that a rating that is below a threshold value specified in BAMS (as outlined in Table 12) triggers multiple re-inspections before it is finally recorded.

Table 17. Summary of Inspection Process by District (July 2003)

District	No. of Bridges	Deck Area (sq ft)	Crew Size	Full Time Inspectors	Part Time Inspectors	File	Clean Form
1	1469	22,247,165	2	23 (3 vacant)	0	Yes	No
2	1000+	7,672,932	2	5 (2 vacant)	2	Yes	Yes
3	875	5,984,029	2	4 (1 vacant)	10	Yes	Yes
4	600	5,460,282	2	3	1	Yes	No
5	875	5,327,749	2	4 (2 vacant)	2	Yes	No
6	970	6,679,801	2	4 (2 vacant)	2	Yes	No
7	734	4,050,026	2	4 (2 vacant)	2	Yes	No
8	900+	8,755,749	2	6 (4 vacant)	6	Yes	No
9	630	3,877,456	2	2	2	Yes	No
Total	~8,000	70,055,189		55			

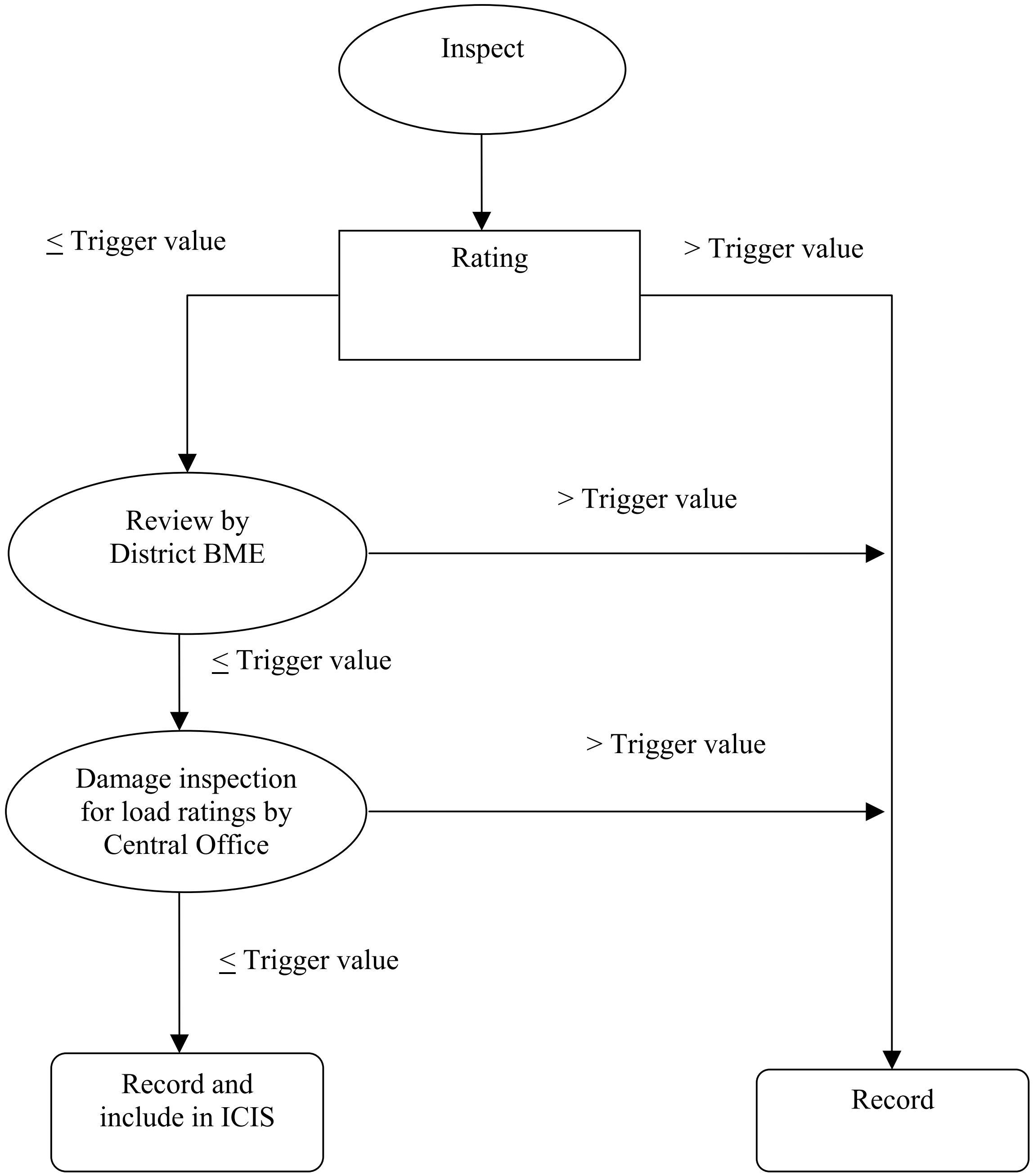

Figure 22. Inspection Process

D.6. Opportunities

The meetings and telephone interviews provided a foundation for some observations and preliminary findings that include:

- Districts follow similar practices in terms of bridge inspection process and data entry

- Quality control is limited to “potential problems”
- There is genuine interest in improving the process
- Extremely variable knowledge and practice of NDE
- Limited resources and the need to inspect many bridges impose constraints on the bridge inspection process..
- There are very different relationships with other units in each of the districts.
- There are many databases and software tools. There is great variability in who has access to which piece data and how familiar in one individual is with a specific piece of software. This also has potential for redundancy and inconsistencies.
- Many of the data issues are part of a series of larger issues related to ownership of data, lack of communication, lack of co-ordination of training, and other organizational and institutional issues.
- PONTIS® essentially serves as a sophisticated filing system for quantities.
- There is a two-tiered inspection process. Bridges that do not exhibit any obvious problems to the inspector are rated, and recorded. Bridges with problems are carefully scrutinized at multiple levels.

While there are opportunities for change, there are clearly some constraints and processes that should be followed:

- No real radical changes outside of current organizational structure.
- New technologies should replicate existing process
- New technologies should follow a well-defined process that includes hardware, software, training, and follow up.

One of the excellent ideas posed by more than one interviewee was that district bridge engineers should share SIMS queries. Most of the district bridge maintenance engineers use SIMS to generate program information and to answer questions. They do not use SIMS frequently and most of them have had very limited training. Sharing queries would give the district bridge maintenance engineers access to a library of queries that could be tailored to suit their particular needs.

There were also some surprises came out of the interviews. The surprises were:

- Some districts loved the Newton Apples
- Some districts would like to have laptops in the field
- Some districts use tape recorders
- Some districts have developed fairly detailed document management systems (e.g. to include digital pictures)
- Many districts interested in piloting new technology

D.7. Recommendations

Based on field visits, a review of IDOT systems documentation and reports, and telephone interviews, our recommendations focus around three areas. The first is a set of general recommendations related to new technology. The second are recommendations regarding non-destructive testing. The third set relate to data acquisition.

General recommendations related to technology

Field personnel are open to new technology and opportunities to improve the bridge inspection process. However, any changes should be in the context of the existing process. That is they should not change how the inspectors to do their job but make their work either easier or better. Introducing any new technology should include not just acquisition of the technology but a well-defined plan for

- Interfacing the technology with existing systems
- Maintaining and updating the technology
- Initial and ongoing training.

Recommendations related to non-destructive testing technology

Non-destructive testing and evaluation is looked at with significant distrust and skepticism. At the same time, the majority (but not of all) of the people we spoke with were not very familiar with NDE/NDT and the potential benefits. Many individuals have had bad experiences with immature technologies or insufficient knowledge of the specific technology. There is also the problem that it is not clear how to fit NDE/NDT into the existing process. That is, there is no “place “ to put the data.

On the other hand, this field is rapidly changing. It is appropriate to explore new technologies, recognizing that adoption of such a technology must follow the general recommendations outlined above.

Recommendations related to data acquisition technology

While a clipboard and paper is a tried and true method for data acquisition, there is a genuine interest among inspectors to try and more sophisticated method for electronic data entry that would support easy "uploading" of data, easy access to historical data and appropriate for field use. The inspectors recognize that advances in technology mean that their "Apple Newton" experience may not be relevant.

We recommend exploration of a wide range of devices including both laptops and PDA's (personal digital assistants). Again acquisition of any technology would be subject to the general recommendations outlined above.

D.8. Attachment: Summaries of Field Visits

IDOT Central Office Bridge Inspection Crew

October 2001

We observed the IDOT Central bridge inspection crew work on the I-55 bridge that crosses the Des Plaines River. The bridge is actually two separate bridges one for northbound traffic and another for southbound each bridge has two lanes. These bridges are steel truss bridges that were recently rehabbed and painted. This bridge is considered a fracture critical bridge due to the steel pins that support the bridge. While we were there the inspection crew was working on the superstructure of the bridge primarily the girders underneath the deck. IDOT's use a snooper truck, which they extend the arm under the bridge to place their inspectors in a position to perform the inspection. The inspection process is mostly visual and reliant on the inspectors' experience.

Central office assembles a logbook before going out to the bridge. The crew reviews the logbook and takes it to the field. It has previous inspection reports and a plan view of the bridge on it first page. Also included is how each element is named, basically by span and position in that span. Then there were sheets of elements where problems were found previously. These forms have blanks next to the last entry so they can be updated. Next in the book are just blanks were elements can be filled in with new problems. This book would be what we need to digitize. The potential to improve this book is limitless and the fact that data can be instantly transferred to a database seems like it would benefit IDOT immensely. As I understand it I believe that this crew waits until winter where inspection is not possible to enter the data they had collected previously inspection season. We definitely need to get one of these books.

The other thing I found interesting were my discussions with the inspectors who seemed to be resistant to change. They could not even tell me what they thought they needed to enhance the performance of their work. Whatever approach we decided on we need to include their thoughts so that the system will be accepted. They do use digital cameras to take pictures of certain defects. Before snapping the picture they write with marker on the element what is its coded name in order to insure the correct location. The question I think we need to ask ourselves is do we design our proposal for central IDOT or for the District level IDOT. Before this decision can be made we must first see what is involved on a district level inspection.

IDOT Central Office Bridge Management

November 8, 2001

Review of "Investigative Study for the Integrated Bridge Management System (BMS)"

This study was a spin-off related to the ISTEA mandates. It attempted to address the fact that data was stored in many different systems and controlled by many different parts of the organization. Document attempted to develop a plan for managing information. Now there are many new people in positions related to bridge management and inspection and the document has no meaning. "Bureau of Information Processing" should be able to provide us with an electronic copy.

The result of this document was some tools to help with data integration and some modifications to computer system development. For example, SIMS came out of this process.

SIMS is essentially a tool for viewing information. There are many different places where the data is entered.

The current status of data integration in Bridge Management System by IDOT

Currently each IDOT district doesn't follow the process described in the 'Investigative Study for the Integrated Bridge Management System'. The PONTIS® Bridge Management System is to be upgraded to the version 4 over the next few months. Each district has developed their own interfaces to the central office and had different bridge inspection and data collection procedures. For examples, not all districts collect element level data. Therefore, the level of experience with PONTIS® varies significantly from district to district.

Relationship between BMS and decision-making.

OP&P assembles the programs. They use a process involving 16 tables that contain information about the bridges in the state. For example, condition states between 1 and 4 represent critical bridges and will ensure that bridges are programmed for replacement. Backlogs and accruing backlogs also influence the process.

Difficulties faced by IDOT on data collection and analysis

Because PONTIS® was originally designed as a network-level management system, IDOT feels that it was difficult to identify different projects and select projects using it. It is important to get each district bridge unit to involved in planning, programming and documentation. Hopefully, version 4.0 is more focused on the project level and is more useful to IDOT.

The other difficulty pointed out is the funding structure and politics in Illinois. Illinois collects a significant gas tax and has much more flexibility as the state is not wholly dependent on Federal funds. This means more flexibility for projects not involving Federal aid. Also, programs such as Illinois First have created resources for transportation projects.

What IDOT wants to do

IDOT hoped that the process of data integration would tighten the link to BMS, and as a tool to impact the bridge management effort in Illinois. This would allow better programming of bridges that values preventive maintenance. They also expect to have more flexibility in terms of using federal dollars for maintenance in the future. PONTIS® should help you do this.

Historically preventive maintenance does not relate to "accomplishment." Therefore we need to see the concept. Focus is 1) Data, 2) Support local decision-making, 3) Support goals for IDOT.

Districts have a lot of autonomy. Generally, there is considerable interest in NDE, but it must be realistic and focus should probably be on deck evaluation.

They also want to find an effective way for optimization, to support the broad goals for IDOT.

Resources

- SIMS Database on CD
- ACCESS database for element level data
- Electronic version of user and technical manuals for SIMS
- PONTIS®

District 1.

November 26, 2001

District 1 is organized somewhat differently from all the other districts. The inspectors assigned to two separate organizational units: a North Inspection unit and a South Inspection unit. They are located in the Elk Grove physically separate from the district 1 main office. This means that all data, information, drawings and photos that are significant are duplicated in both the field office and the district office. Bridge repair *responsibilities* including maintenance and special services such as moveable bridges are located at Elk Grove and Joliet.

Each group keeps bridge files by bridge number. A typical file includes historical inspections, and correspondence. Plans are kept separately. Inspectors review past inspection reports before going into the field and will often bring the report and plans to the field.

Notes regarding forms:

- Pink forms represent PONTIS® inspections. Only one person in each section enters PONTIS® data.
- New inspection form for NBIS data. Have electronic and paper copies of each form.

Bridge inspection process:

- Review file
- Take file to field
- Make notes of structure while inspecting with clipboard
- Take necessary photos of structure
- Fill in form (form is a 5-year cumulative form including proposed maintenance)
- Data entered in MMI including proposed maintenance with priority levels (1, 2, 3)

Notes on data entry:

- Data is entered into MMI and uploaded nightly into ISIS
- SIMS is generated from ISIS
- Not all inspectors have access to SIMS
- MMI has comment field. Comments are required for all low ratings.

Notes regarding inspections:

- Some fracture critical and underwater inspections are done in the district.
- District has portable sonar unit (since 1986) to do streambed profiles but generally inspectors will probe.

Notes on how the data are used:

- Data is collected at the district and includes documentation and pictures.
- Low ratings trigger action in Springfield.

- Additional data may be collected (e.g. section loss)
- Analysis is completed to define ratings (usually a consultant)
- Inventory is updated

Issues:

- Need to differentiate between new and older bridges
- There are problems with bridges with different components with different ages due to widening or other improvements. (This issue should be solved using updated PONTIS®.)
- Need rich comments.

Notes on experience with Newton Apples:

- Handwriting recognition poor
- Easy to carry
- Being able to enter data in the field was great
- Software was great
- Uploading was difficult (required travel to Schaumberg)
- Just used for PONTIS® data

Bridge Inspection

We accompanied an inspector to a 4 lane simple span bridge over a creek.

District 2

January 3, 2002

At District 2 the entire bridge maintenance team is located in a large open room. The Bridge Maintenance Engineer took interest in my questions and answered most of them while the others in the working environment would chime in with their perspective. District 2 covers 12 counties with over a thousand structures with spans greater than 20 ft in their care, 193 of those structures are culverts. They have five full time inspectors. They perform over 90% of the inspections with this group. They do hire two part-time off-season construction workers from

December to March. These workers have been with the office for quite some time. The reason that they like having as few part time workers as possible is because that they feel that they know the bridges and the conditions to watch out for. They do take pride in this fact. They do not use highlighting reports but they essentially do the same thing just with word of mouth communication. If an inspector finds something that he would like to lower the NBI rating to a five or lower, the change requires approval from a senior engineer. They do make notes on deck overlay and add them to the inspection because the NBI or PONTIS® data collected does not help them decide which bridges need a new overlay. They did have some experience with the Apple Newton's but no one in the office could take anything positive from the whole experience. They found it more time consuming then beneficial and did not use them beyond the short test period. Also fundamentally they report to practice a different style of complete nonbiased approach in their bridge inspections. They look at no old records until after they have finished rating the bridge on the site. They believe that the looking at the old inspection form gives the inspector an opportunity to be lazy and potentially causes the inspector to look over flaws in the bridge.

So far, with maybe the exception of central IDOT crew they use the most NDT technology. The list includes ultrasonic testing, Mag-particle, thickness gauges, sonar, rebar finder and dye penetrate. They also have available a snooper truck. Programming is done using the NBI numbers based on IDOT central protocols determining what NBI values are acceptable before the bridge needs to be scheduled for repair. After this is done then the budget comes into play to decide to what extent of the proposed program can be fulfilled.

When asked what they could use they only wanted more manpower in the office. They were extremely grateful to central IDOT and considered them to be very cooperative whenever they need help. The only complaint they had was that on the district level they did not understand why they were doing CAD work for contracts. They found this to be a waste of their time and not their work wondering why design did not handle this.

Field Inspection

In the field, we inspected two bridges that cross over Interstate 80 near Geneseo. These bridges are on rural roads that see little traffic. Also they are not heavily salted and are in relatively good shape. The bridge inspection engineer has held this position for three years now. Before that he was employed by IDOT as a construction engineer. He had been with that department for around 20 years. When the inspector arrives at the bridge, he first takes out the bridge drawings and spends a few minutes looking at the sheets. He told me he is looking at the particular design and problems that are associated with it. Then he gets out the car and walks the length of the bridge top and bottom. This is just to look for any irregularities compared to the drawings or unearth any surprises waiting for him. Then he returns to the car and begins to code the bridge for PONTIS® inspection. He accessed the PONTIS® coding book and describes the process. When doing this, it was clear that to properly code the bridge element is not as easy as it sounds. The number of different subcategories is surprising. On the back of the PONTIS® inspection form he prepares a sketch of the bridge (nothing to fancy). Then after this is done he takes his steel clipboard with PONTIS® inspection form held on in the front, and begins the serious inspection. He spends about thirty minutes on this portion taking notes and also filling in the prepared sketch. The whole process ended with a chain drag over the deck (the low traffic volume made this possible). Then he returns to his car and spends about 10 minutes calculating the quantities of the bridge and then filling in the PONTIS® sheet. Then he does the NBI inspection at this point. He does not need to get out of his car. He takes out the NBI sheet and reviews a rather old (1984 version) of what particular NBI values represent. After he has assigned the NBI number, he reviews the old numbers as a check. It was interesting to see that at one point, he rated the bridge higher than the old number it had been rated. Theoretically this mean the condition improved. The number only moved up one and he told me he could see how the other inspector rated the bridge lower. This process held true to the fact that Mahmoud reported that they do not look at old inspection data before they inspect. The above report holds for both bridges we reviewed.

The surprising thing to me was that NBI numbers were used as the programming data. Even though little effort was put into the number, but the PONTIS® data that they collected carefully was left mainly unused.

District 3.

December 27, 2001

District 3 has three full time inspectors and the bulk of work is done by nine part time seasonal worker coming from the construction field. They begin around November and continue working till around March. The bridge repair technician estimated that 90% of the bridges inspected that year are done in this period. The Bridge is not really scheduled for inspection. An inspector will come in and grab all the files for a certain area and go out and do those and then come back and grab another pile and return the old files. Another interesting fact that applies to this district is that 100% of the bridges are inspected every year. Each time an inspector lowers a rating below a six they have to use a highlighting report. A highlighting report basically consists of a blank sheet where an inspector describes in words and sometimes attached photos of the particular problem of why the rating was lowered. At this point one of the higher-level officials in the office will review the file and maybe even travel to the bridge and determine if the rating deserves to be lowered.

NBI information is what is used when programming is done, which is performed Bridge Maintenance Engineer and the programming department. The PONTIS® information collected is not used for the programming. It has other uses such as looking up quantity values for estimating.

The Apple Newton's were not well accepted by some and saw little use in this district. A few of the younger workers like the idea of the PDA devices but were not happy with the performance or the limited memory of the Newton. Many problems were persisted with the entering the data. Training was considered pretty much non-existent. They were never used more than a couple of months.

While on the inspection I noticed that the inspector refereed to the IDOT bridge inspection manual for NBI descriptions to understand exactly what a five rating is on a bridge deck or etc. He also looked quite often at the PONTIS® coding book for coding numbers and condition descriptions.

District 8.

December 18, 2001

IDOT district 8 has 900 bridges. They do bridge inspections mainly in January, February and March (about 60% of total bridges). During these 3 months, they employ temporary inspectors from the construction field. IDOT allow for the temporary employment only at this time. These people that come from the construction field have also have received NBI and PONTIS® training.

In the field they collect NBI data and PONTIS® data at the same time, however, they seldom use PONTIS® data for any decision-making and are mainly employed in just collecting and recording information. This was a main complaint about PONTIS®: the inspection added work and added little benefit. The PONTIS® version installed in District 8 office is Windows based and uses Microsoft Access software. It was only installed a couple of months ago. District 8 people use it only for entering the data. They did try to print out inspection forms but it was not functioning properly.

District 8 has some of its own systems that they have developed for truss design. They have developed an access database to report the condition and notes. This database is shared in the office and also with the people of central office. It found much favor in the office but the central has not begun to utilize it.

District 8 used Newton Apples for a year. District personnel reported that there was a big problem for the field data transfer from Newton Apples to their IBM desktops. Someone from central came down more than once but the problem still persisted. The inspectors never trusted fully the Newton Apples and they also kept paper forms during the inspection while they used the Newton. Tim said its small memory limited it to containing the information collected at the site. So old inspection information could not be accessed at the site.

Regarding NDT, personnel said they use mag-particle and some other methods when they do inspection. They do have ultrasonic devices but seldom use them. The reason is the use of this device is complex and users need training. Central IDOT only provided them with the equipment but no one has been trained at this point.

When the ratings of the superstructure, deck or substructure are at a 5, district 8 tries to put them into 5-year-program. When they drop to 4, they become critical and must have a very good reason not to be scheduled. The programming they do is all done by Don Oller and the programming department of District 8 with NBIS data.

A major difference between district 8 and district 1 that I noticed was the location of the office. District one Bridge maintenance inspectors and engineers are located in a pole barn at a salt distribution / maintenance yard. District 8, bridge maintenance office is located in the district headquarters. The sense I got from the District 1 was that people thought that the people in headquarters were not respectful of them and their needs for equipment were not being addressed. That was not the sense at all in district 8. They provided me they seemed to have a good cooperation with the others in the district. Their complaints were more with central office not allowing them to hire more people and not being helpful to their problem but continuously demanding performance out of them.

Field Inspection

The regular inspection they took us to was a dual structure bridge. One bridge handled traffic flowing one way and the other flowing the other way. Recently one of these bridges was replaced completely and the other had some rehabilitation work done to it. The work was required mainly due to subsidence of the bridges due to the fact of a nearby abandon coal mine.

We were also taken to a fracture critical bridge by St. Louis called the Popular Street complex, which are basically large feeder ramps that guide traffic to a larger bridge that crosses the Mississippi. The bridge inspector showed us the amount of paperwork and documentation that was necessary. Also he pointed out the type of repairs that were done to this bridge. This day they were testing a new bucket truck that they were thinking about exchange for their old one with central IDOT. They again at this point really displayed that it is more of a team environment. Everyone had his say during the discussion.

Crews of at least two inspectors do inspections. They go to a bridge and they both walk along the bridge inspecting it. One took the PONTIS® sheet the other takes the NBI sheet.

When we asked bridge maintenance engineer what he would like to improve his job he thought that a paperless system would be excellent but he had his doubts if it could actually implemented. Stating that there would be a good amount of opposition to it due to the previous unsuccessful Newton apple. Also the amount of work that would be required to digitize old record to make them available to the inspector would be a tremendous amount of work and file size would also be an issue. In general though he liked the potential of the system.

APPENDIX E.

PRACTICES IN OTHER STATES: SUMMARY OF RESPONSES TO THE SURVEY

E.1. Introduction

To understand what is happening in other states and go beyond what is documented in the literature, we developed a survey that was administered by IDOT. The survey was developed with input from the Technical Review Panel. Members of the Technical Review Panel pretested the survey. The survey and cover letter are can be found in APPENDIX C.

The survey was emailed to the National RAC (AASHTO's Research Advisory Committee) listserve contact in each state. They were asked to forward the email to those in the state that are responsible for bridge inspection and rating assessments.

The survey focused on the following areas:

- Type of routine inspection
- Who conducts inspections
- Time taken for a typical inspection
- Where the data entry is done
- Time required for data entry
- Number of inspectors and number of bridges
- Size of typical inspection team
- Qualifications of inspectors
- Databases used
- Bridge management system used
- Devices used for data collection
- Non-destructive testing technologies
- Use of bridge monitoring and remote monitoring
- Ongoing research

The survey was designed to be completed in less than 15 minutes.

IDOT received responses from the 28 states are listed in Table 18. The following sections document the responses.

Table 18. States Responding

States Responding[2]		
Alaska	Maryland	Ohio
Arizona	Michigan	Oregon
Arkansas	Missouri	Pennsylvania
Connecticut	Mississippi	Rhode Island
Delaware	Montana	South Carolina
Georgia	Nebraska	Utah
Illinois	Nevada	Virginia
Indiana	New Hampshire	Washington
Iowa	New Mexico	
Kansas	New York	

E.2. Responses

The following charts (Figure 23 through Figure 31) summarize the responses received from the various states. Note that for many questions respondents were able to check more than one response so that the percentage of respondents represents the percentage checking that specific response.

The following observations are made based on the data provided by the states responding to the survey:

- All but one state undertakes NBI inspections.
- All states use DOT employees for routine inspection.
- Many states use some combination of employees and contracts for inspection.
- Inspection of a typical bridge takes 1-4 hours and data entry typically takes less than an hour.
- The typical inspection team consists of two inspectors.
- Almost 70% of responding states use PONTIS.
- The majority of states using PONTIS® use Oracle as their database.
- Almost 60% of responding states regularly laptops for field data collection.
- Ultrasonics is the most commonly used non-destructive testing technology.

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[2] Since the responses of the State of Missouri and New Hampshire are unusable, we do not include them in our summary.

In addition on question identified where data entry was undertaken, and four others questions on the survey had yes/ no answers. These are summarized in Table 19 and Table 20.

Overall, the results are not surprising and fairly consistent with the reported national trends.

We also summarized the responses in terms of state specific responses related to the use of innovative technology (including laptops). Table 7 documents these responses. Based on this table, the research team is made follow-up phone calls.

Table 19. Location of Data Entry

Question	Field	Office	Both
4. Is the data entry done in the field or office?	42%	38%	20%

Table 20. Summary of Yes/ No Responses

Question	Yes	No	No Response
14. Does your state undertake Large Scale Monitoring of bridges?	17%	75%	8%
15. Does your state undertake Remote Monitoring of bridges?	17%	83%	0%
16. Do you have any ongoing research on bridge inspection, data collection or data management?	75%	21%	4%

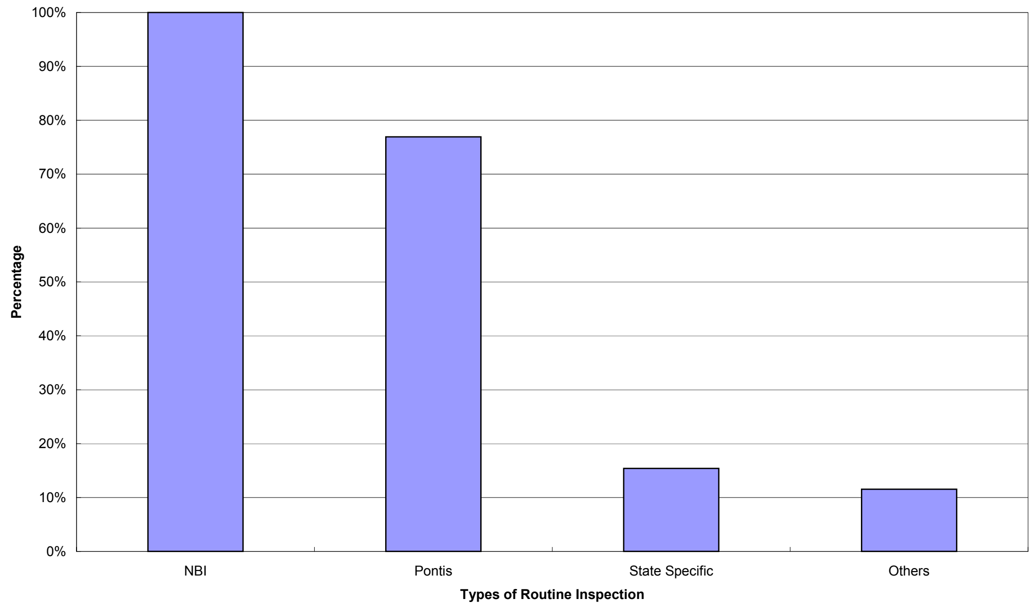

Figure 23. Question 1. What types of routine inspection is undertaken in your state?

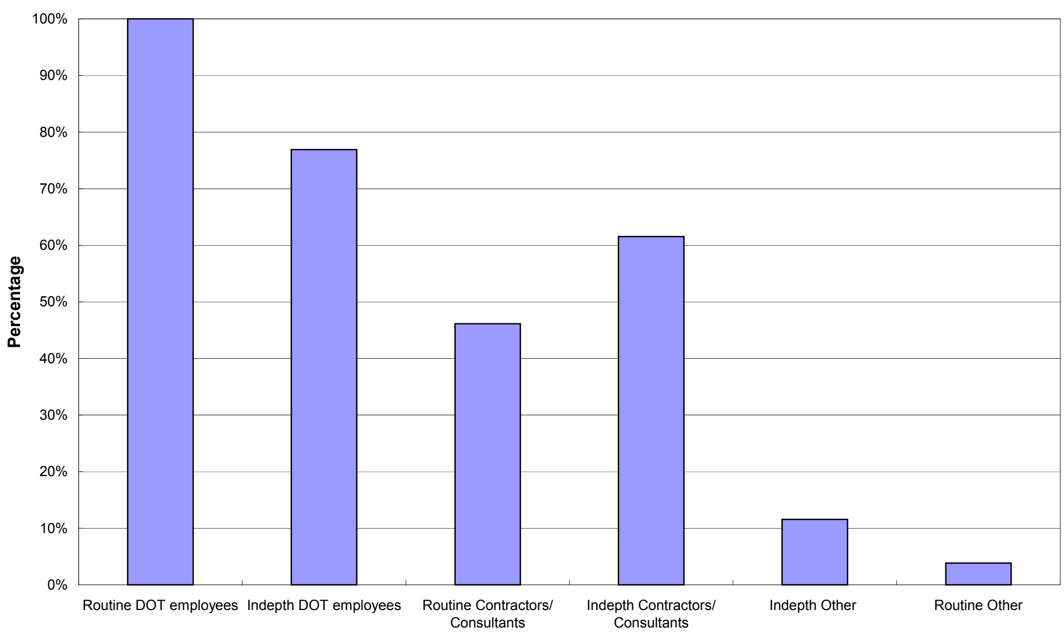

Figure 24. Question 2. Who conducts inspections?

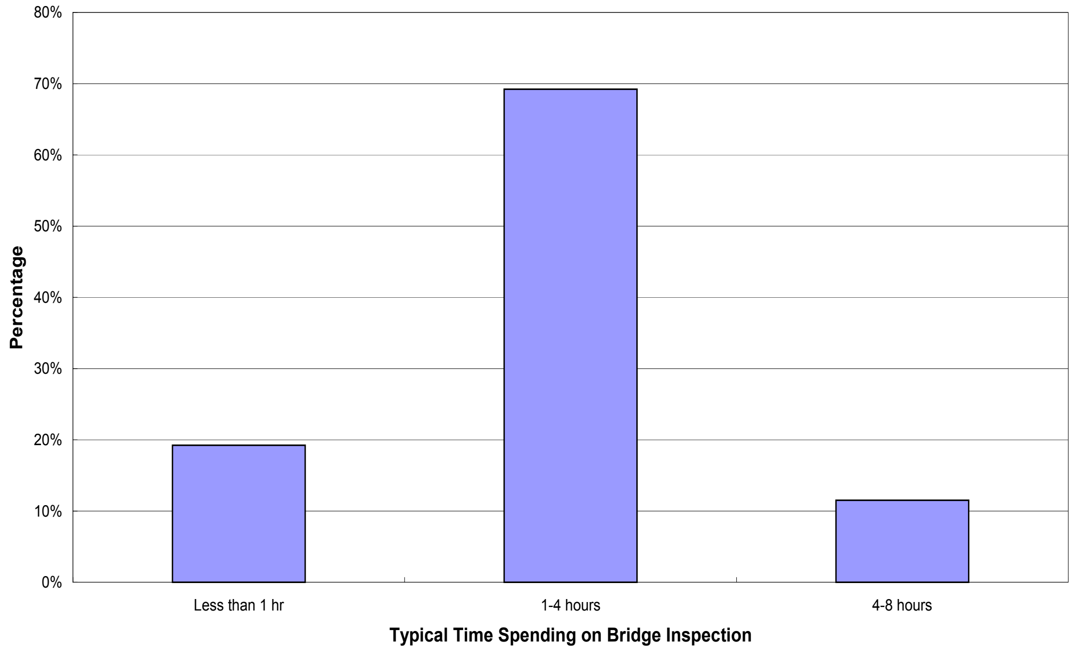

Figure 25. Question 3. What is the typical time spent inspecting a bridge?

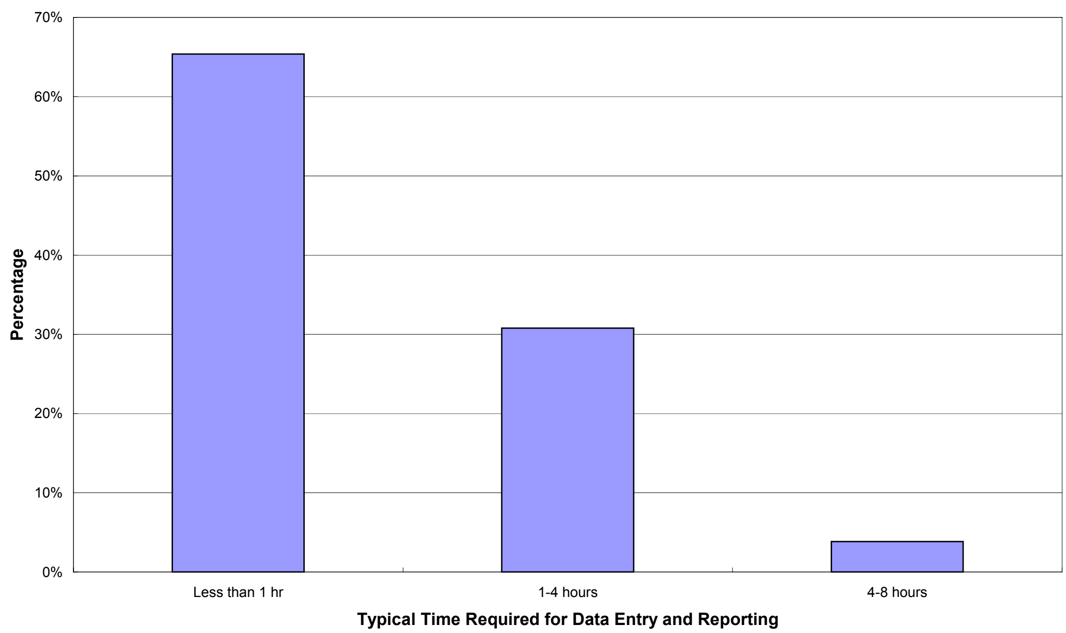

Figure 26. Question 5. What is the typical time required for data entry?

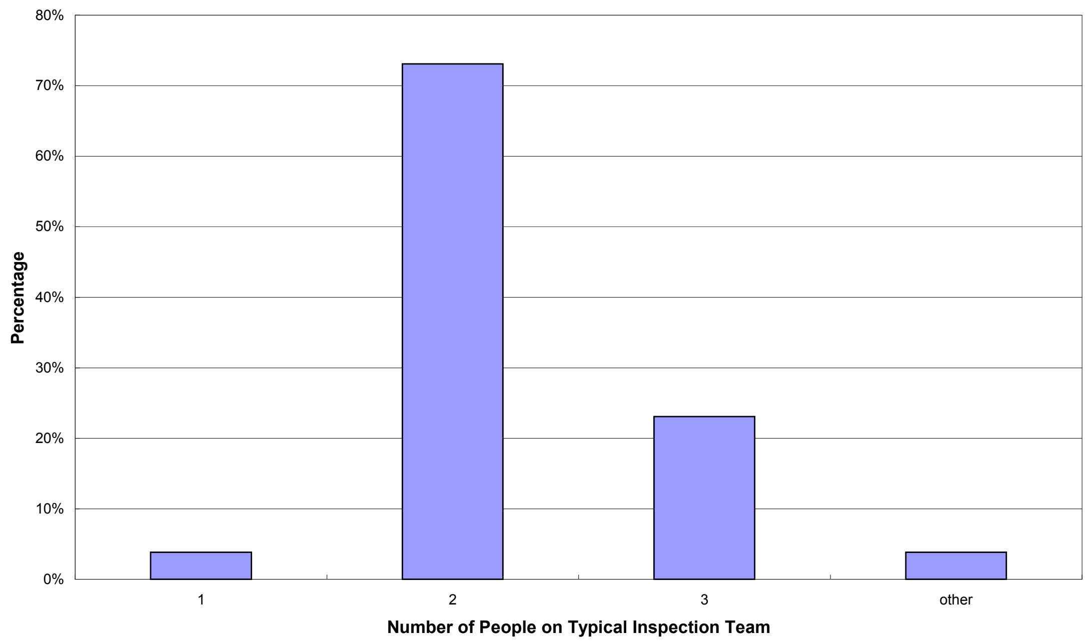

Figure 27. Question 8. How many people are on a typical inspection team?

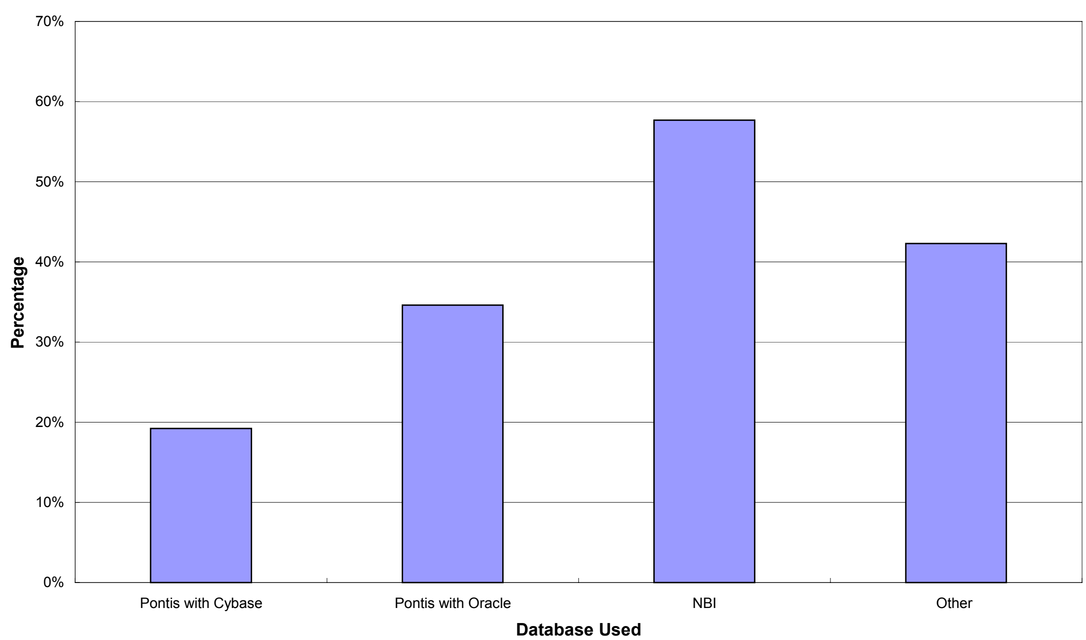

Figure 28. Question 10. Which databases are used in your state?

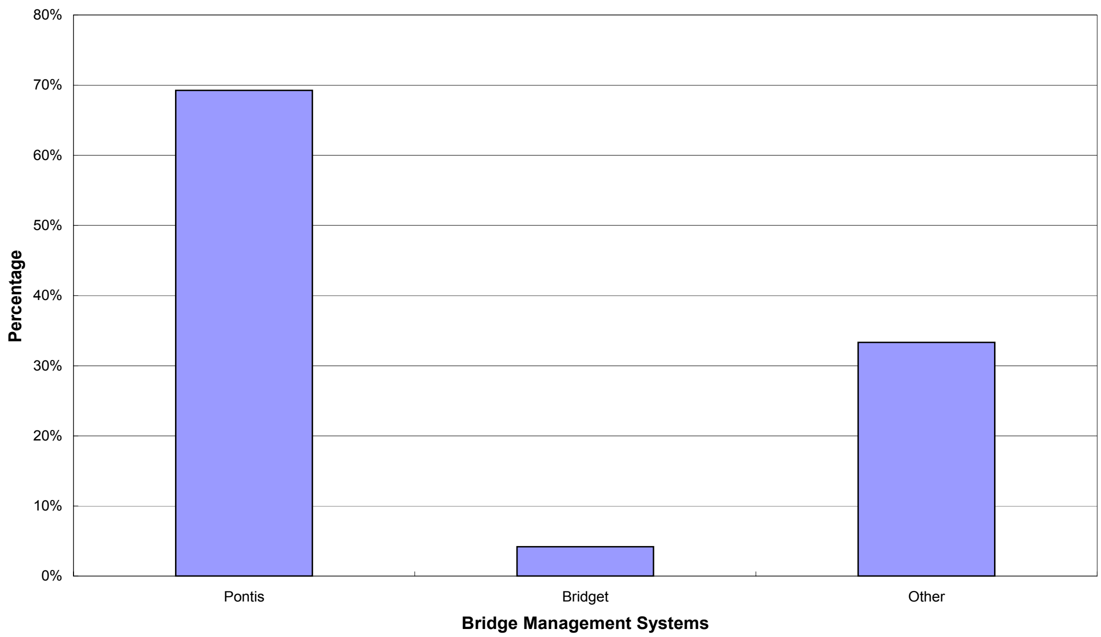

Figure 29. Question 11. Which bridge management systems are used in your state?

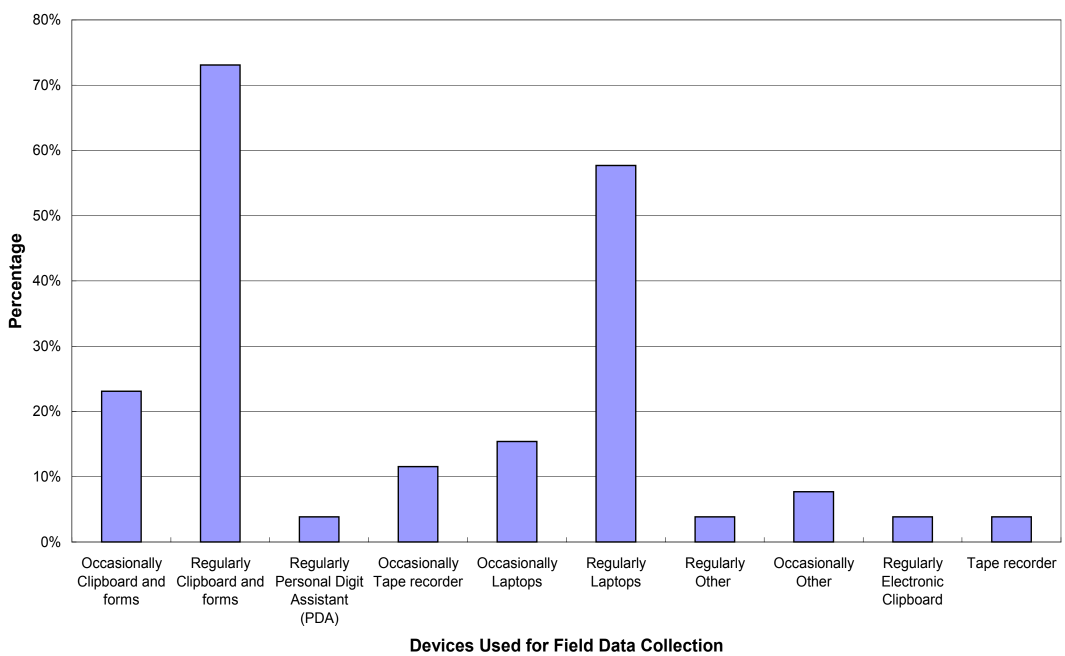

Figure 30. Question 12. What devices are used for field data collection?

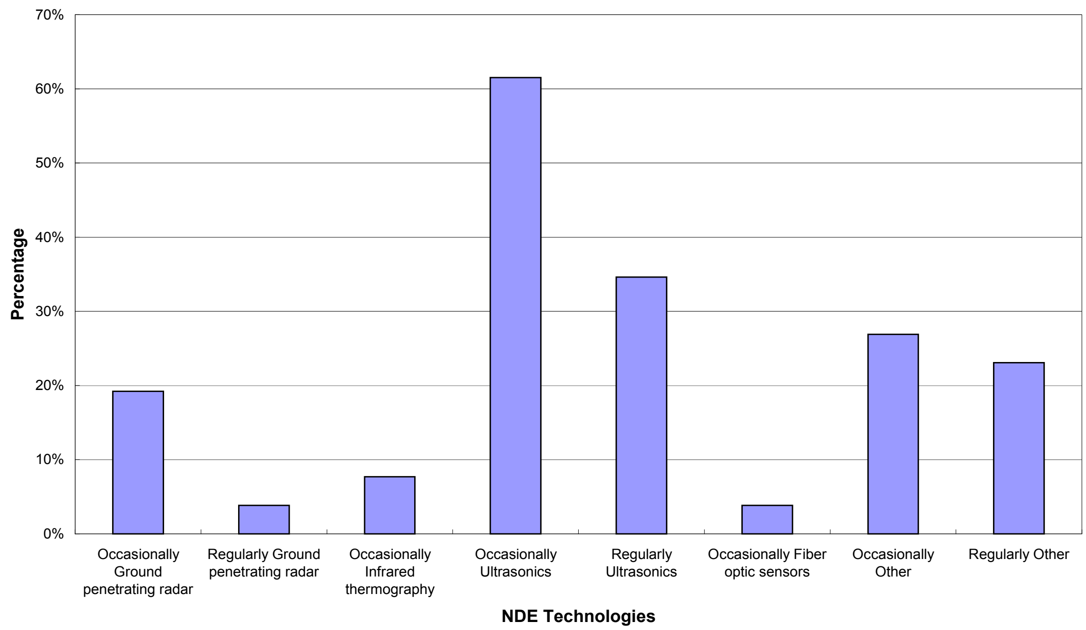

Figure 31. Question 13. Which non-destructive testing technologies do you use?

Based on the survey results, we then followed up with selected states using "interesting" technologies to find out more about how they were using them. The questions used for the telephone interviews may be found APPENDIX C.

No new non-destructive testing technologies or bridge monitoring activities were revealed in the survey.

Table 21. State Specific Responses

District	No. of Bridges	Deck Area (sq ft)	Crew Size	Full Time Inspectors	Part Time Inspectors	File	Clean Form
1	1469	22,247,165	2	23 (3 vacant)	0	Yes	No
2	1000+	7,672,932	2	5 (2 vacant)	2	Yes	Yes
3	875	5,984,029	2	4 (1 vacant)	10	Yes	Yes
4	600	5,460,282	2	3	1	Yes	No
5	875	5,327,749	2	4 (2 vacant)	2	Yes	No
6	970	6,679,801	2	4 (2 vacant)	2	Yes	No
7	734	4,050,026	2	4 (2 vacant)	2	Yes	No
8	900+	8,755,749	2	6 (4 vacant)	6	Yes	No
9	630	3,877,456	2	2	2	Yes	No
Total	~8,000	70,055,189		55			

APPENDIX F.

STATES USING LAPTOPS AND HANDHELD DEVICES: WORKING PAPER

F.1. Background

Based on responses from 27 states to an email survey on bridge condition assessment and inspection practices, we identified 15 states that were using laptop and handheld computers to support their data collection. This working paper documents that responses obtained during telephone interviews to a predefined set of questions. Thirteen of the states are reported in the form of the responses to questions. Two states are simply transcripts.

The questions used for the telephone interviews may be found in APPENDIX C.

F.2. Alaska

Date: 7/12/02

1. How are you using the laptops in the field?

The system is used for field collection of data. Collect hydrology data and rail and signage data. Some structural programs are on the laptops for use of some of the engineers.

2. Describe the system?

The system was previously just a Microsoft Access that held NBI, PONTIS®, comment space, and digital photos. Recently this spring PONTIS® 4.0 was added to these laptops recently.

3. How does the laptop interface with other systems? (mainframe, database, PONTIS®, as appropriate)

The laptop is brought in from the field to the central location where all the bridge inspections work out. There the laptop is connected to the mainframe where the completed inspections are uploaded and the next batch of inspections to be performed are downloaded.

4. How long have you been using it?

7-8 years on the in house access software. Less than 6 months for PONTIS® 4.0

5. How widely is the system implemented (geographically and by whom)?

Whole state every inspector is required to use system.

6. How widely is the system used (geographically and by whom)?

Whole state every inspector is required to use system.

7. Describe the development process?

The Access based system original was developed directly from the paper forms. But as time went on extra features were added such as a photo log that each "access page" that can store four photo with description underneath.

PONTIS® 4.0 was brought on because of it superior long-term planning capabilities and models. The software provider AASHTO can modify certain fields but they haven't used this system long enough to know what changes need to be made. So right now they are using the "canned" version.

8. What kind of training do you have, how frequently is it offered, what is the duration, who provides it?

Most training is informal and done in the field but at first the new inspectors are taught at the office the Access system initially. The PONTIS® has been more trial and error since it was not developed in house and no one is an expert in the office.

9. Do you use specialized hardware? If so are there specific models or configurations? Is there anything you would not recommend?

The system uses regular Dell Inspron laptops that run with 400 MHz. Have work out for us and proven to be reliable.

10. Describe your software?

NA

11. Do you customized or off the shelf software?

Customized the Access software system and plan later to customize the PONTIS® 4.0

12. Do you consider the system reliable?

Yes they consider it very reliable but they still keep a paper copy back up.

13. How do you maintain and upgrade the system?

NA

14. Do you have any written or electronic material?

No

F.3. Arizona

Date: 7/16/02

1. How are you using the laptops in the field?

The laptops are being used in the field by the inspectors to record field data. This is done in the trucks not on the actual bridge site. The name of the system is ABIS

2. Describe the system?

The system collects NBI, PONTIS®, and other typical Arizona information. They check out a portion of the database about a week's work but that doesn't really mean any particular bridge.

3. How does the laptop interface with other systems? (mainframe, database, PONTIS®, as appropriate)

The system uses "check in/check out" type of communication. The portion that is checked in is what the inspector has completed for the previous week and the portion checked out is what he will complete for the upcoming week.

4. How long have you been using it?

Using laptops since 94. The software schemes have changed several times over that period

5. How widely is the system implemented (geographically and by whom)?

99% of the inspections are performed using this system

6. How widely is the system used (geographically and by whom)?

99% of the inspections are performed using this system

7. Describe the development process?

They first used a system called d-base. It allowed you to report conditions. Also it allowed an interface for comments. Arizona went through several generations of this software that FHWA developed. Then in 1998 they switched to an in house program that they developed called ABISS. It is a Access based software to store PONTIS® and NBI

8. What kind of training do you have, how frequently is it offered, what is the duration, who provides it?

Mostly now new inspectors might get a day of training but for the most part training is done in the field. The team of inspectors is made of three people: one inspector, a licensed engineer, and a technician.

9. Do you use specialized hardware? If so are there specific models or configurations? Is there anything you would not recommend?

NO

10. Describe your software?

Software is just a database for the most part and has little analysis capabilities but does have photo storage abilities to help organize the inspection

11. Do you customized or off the shelf software?

NA

12. Do you consider the system reliable?

Reliable

13. How do you maintain and upgrade the system?

NA

14. Do you have any written or electronic material?

No

NOTE: Changes in inspection coding book could fundamentally cause their software to become of no use. This could cause the switch to PONTIS® completely

F.4. Arkansas

Date: 7/12/02

1. How are you using the laptops in the field?

The system is used for field collection of data. Also, collect hydrology data, and rail and signage data. Some structural programs are on the laptops for use by some of the engineers.

2. Describe the system?

The system was previously just an Microsoft Access that held NBI data, PONTIS® data, comment space, and digital photos. Recently (this spring) PONTIS® 4.0 was added to these laptops recently.

3. How does the laptop interface with other systems? (mainframe, database, PONTIS®, as appropriate)

The laptop is brought in from the field to the central location where all the bridge inspections work. There the laptop is connected to the mainframe where the completed inspections are uploaded and the next batch of inspections to be performed are downloaded.

4. How long have you been using it?

7-8 years on the in house access software. Less than 6 months for PONTIS® 4.0

5. How widely is the system implemented (geographically and by whom)?

Whole state, every inspector is required to use system.

6. How widely is the system used (geographically and by whom)?

Whole state, every inspector is required to use system.

7. Describe the development process?

The Access based system original was developed directly from the paper forms. But as time went on extra features were added such as a photo log that each "access page" that can store four photo's with description underneath.

PONTIS®4.0 was brought on because of it superior long-term planning capabilities and models. The software provider, AASHTO, can modify certain fields but they haven't used this system long enough to know what changes need to be made. So right now they are using the "canned" version.

8. What kind of training do you have, how frequently is it offered, what is the duration, who provides it?

Most training is informal and done in the field but at first the new inspectors are taught in the office to use the Access system. The PONTIS® has been more trial and error since it was not developed in house and no one is an expert in the office.

9. Do you use specialized hardware? If so are there specific models or configurations? Is there anything you would not recommend?

The system uses regular Dell Inspron laptops that run with 400 MHz. Have worked out for us and proven to be reliable.

10. Describe your software?

NA

11. Do you customized or off the shelf software?

Customized the Access software system and plan later to customize the PONTIS® 4.0

12. Do you consider the system reliable?

Yes, they consider it very reliable but they still keep a paper copy back up.

13. How do you maintain and upgrade the system?

NA

14. Do you have any written or electronic material?

No

F.5. Delaware

Date: 7/10/02

1) How are you using the laptops in the field?

Inspectors enter both PONTIS® and NBIS data into the laptop in the field.

2) Describe the system?

The system is provided by AASHTO it basically is PONTIS® 4.0

3) How does the laptop interface with other systems? (mainframe, database, PONTIS®, as appropriate)

Bring back to the office and information is uploaded for next set of inspections and the information of the completed inspections is downloaded.

4) How long have you been using it?

4 years

5) How widely is the system implemented (geographically and by whom)?

Entire state

6) How widely is the system used (geographically and by whom)?

Entire state. Delaware is not such a big state. It sounded like he was doing the office connection of mainframe to laptop for entire state.

7) Describe the development process?

Developed by AASHTO has no idea.

8) What kind of training do you have, how frequently is it offered, what is the duration, who provides it?

AASHTO comes in periodically and trains people on new features, continuous training.

9) Do you use specialized hardware? If so are there specific models or configurations? Is there anything you would not recommend?

NO

10) Describe your software?

11) Do you customized or off the shelf software?

Not customized

12) Do you consider the system reliable?

Very reliable

13) How do you maintain and upgrade the system?

AASHTO new version are the upgrades to system or new laptops when necessary

14) Do you have any written or electronic material?

None

F.6. Georgia

Date: 7/12/02

1. How are you using the laptops in the field?

They have been involved in an electronic inspection process since 1996. The system is virtually paperless. Laptop care used to collect the inspection information in the field. Also digital photography is stored on these laptops.

2. Describe the system?

There are four bridge maintenance engineers throughout the state who have three teams of inspectors working under them. The team of inspectors come in and have a database of bridges downloaded to their laptops. This database is based usually on a particular county and on average holds around 80 bridges.

3. How does the laptop interface with other systems? (mainframe, database, PONTIS®, as appropriate)

The laptop must be brought into one of the regional offices where the information is downloaded to headquarters. After it has been uploaded to the BME, the supervisor for the inspection team has to sign off on all the inspections. This was done I was told by looking at the notes and the ratings and to see if the are in agreement. The software has the power to sort through the data and group things based on fields but does not compare old inspection data with the new and flag bridges.

4. How long have you been using it?

Since 1996

5. How widely is the system implemented (geographically and by whom)?

Statewide

6. How widely is the system used (geographically and by whom)?

Statewide all inspectors are required to use this system

7. Describe the development process?

In 1996 it was decided that a paperless system would be the best. The software was developed with the help of an outside consultant and with a few weeks of training and a lot of field experience the system has been perfected..

8. What kind of training do you have, how frequently is it offered, what is the duration, who provides it?

A few weeks at the beginning of the system use and in the field since

9. Do you use specialized hardware? If so are there specific models or configurations? Is there anything you would not recommend?

No

10. Describe your software?

NA

11. Do you customized or off the shelf software?

Customized

12. Do you consider the system reliable?

Very reliable

13. How do you maintain and upgrade the system?

Just upgraded recently and added new features. Such as digital photography

14. Do you have any written or electronic material?

NONE

F.7. Kansas

Date: 08/22/02

48) How are you using handhelds in the field?

Been using handheld computers for 6 years now. Only for PONTIS® level inspections this is an element level inspection. Another form is used to collect NBIS information/

49) Describe the system?

Fujitsu handheld computers that work with a menu based software to fill in ratings and quantities for elements.

50) How does the handheld interface with other systems? (mainframe, database, PONTIS®, as appropriate)

Done electronically at the office cant really fill us in much more on the technical side.

51) How long have you been using it?

6 years

5) How widely is the system implemented (have equipment and software for using handheld devices) (geographically and by whom)?

Whole state

6) How widely is the system used (as in actually make use of the hardware and software) (geographically and by whom)?

Whole state

7) Describe the development process?

In house development that focused on PONTIS®.

8) What kind of training do you have, how frequently is it offered, what is the duration, who provides it?

Training at first involved tutorials on the handheld themselves. All other training came from inspectors teaching each other

9) Do you use specialized hardware? If so are there specific models or configurations? Is there anything you would not recommend?

Fujitsu handheld

10) Describe your software?

Menu based software for elements

11) Do you use customized or off the shelf software?

Customized internally

12) Do you consider the system reliable?

Very reliable had some bugs but have worked threw them but we are going back to a paper form that will involve one inspection form instead of doing two inspection as now (NBI & PONTIS). Environmental factors such as sun, wind, and etc he believes inhibit the use of a pen based computer to work well for a NBIS type inspection that requires notes. Does use PONTIS® data to help form a health index and do some forecasting but not involved in modeling. Believes it is *better use of his high dollar individuals in the field doing inspection then trying to enter data. So he will be switch to a clerical worker to enter the data from the paper forms into the computer system. In the field one worker will work as the collector of information and the others will have freedom to work with hands for chain drags, measurements, and etc.*

13) How do you maintain and upgrade the system?

No plans to upgrade because of switching back to paper

14) Do you have any written or electronic material?

None

F.8. Maryland

Date: 7/16/02

1. How are you using the laptops in the field?

The laptops are located in the van. The inspector takes a blank form that he printed out from the laptop in the van. The inspectors perform the inspection and then return back to the truck and fill out an Access based program into which NBIS and PONTIS® data is entered. Also a photo log system that runs separate to Access based system is available to inspectors in the van. This database is available to download new photos to. The numbers of pictures are predicated by the condition.

2. Describe the system?

The system is not a check in check out system in the sense that the whole database is located on laptop and they don't exchange data and up load when they come in but do this on a scheduled basis.

3. How does the laptop interface with other systems? (mainframe, database, PONTIS®, as appropriate)

Schedule uploads and downloads times to synchronize databases and photos.

4. How long have you been using it?

Using laptops in field since 93 on a system called Informix, switched to Access based system in 97.

5. How widely is the system implemented (geographically and by whom)?

All in the state

6. How widely is the system used (geographically and by whom)?

All in the state

7. Describe the development process?

In house developed system. Similar to what was used before built around PONTIS® and NBIS collection needs. The digital photo log has been in use for only 6-months. Developed out a desire to completely stop using film.

8. What kind of training do you have, how frequently is it offered, what is the duration, who provides it?

In house training. Some classes on Access. Most training by other team members

9. Do you use specialized hardware? If so are there specific models or configurations? Is there anything you would not recommend?

No

10. Describe your software?

Access based software

11. Do you customized or off the shelf software?

Customized Access

12. Do you consider the system reliable?

Reliable but consider a good amount of maintenance and work, gets easier with some background

13. How do you maintain and upgrade the system?

Continuous upgrade process because of federal changes.

14. Do you have any written or electronic material?

None

F.9. Montana

Date: 7/9/02

1. How are you using the laptops in the field?

Were using them for remote field entry of the data through the web.

2. Describe the system?

In house developed web base system has been used for three years

3. How does the laptop interface with other systems? (mainframe, database, PONTIS®, as appropriate)

The inspector connects through the web to the mainframe, which allows for download and uploading of information. It is not a wireless web type situation but the inspector must call in through regular phone line

4. How long have you been using it?

3 years

5. How widely is the system implemented (geographically and by whom)?

It is all over the state but about 50% (just a estimation that I suggested) use the system. The others still use the hardcopy forms and come back to office and fill out from there.

6. How widely is the system used (geographically and by whom)?

It all over the state but about 50% (just a estimation that I suggested) use the system. The others still use the hardcopy forms and come back to office and fill out from there.

7. Describe the development process?

Doesn't know too much about development just that it was developed in house.

8. What kind of training do you have, how frequently is it offered, what is the duration, who provides it?

Not involved in process doesn't know much about what went on

9. Do you use specialized hardware? If so are there specific models or configurations? Is there anything you would not recommend?

No specialized hardware just a regular laptop and modem

10. Describe your software?

Web Based software is available to view on the web.

11. Do you customized or off the shelf software?

Customized

12. Do you consider the system reliable?

Never used it can't make a judgment

13. How do you maintain and upgrade the system

The system was updated recently for the first time in February he believes.

14. Do you have any written or electronic material?

http://webdb2.mdt.state.mt.us/pls/bms_pub/PONTIS40_site.htm

This site is good, but a little awkward to navigate at first. It only requires explorer and acrobat to have access to tremendous range of data. Seem to be like the model IDOT is approaching so should keep this state in mind for sure. He also reported that they were thinking of using PDA but haven't found exactly the system they were interested.

F.10. Nevada

Date: 7/19/02

1. How are you using the laptops in the field?

Each bridge inspection engineer takes computer to the field. Tried for a while to use the laptop on the actual bridge site but glare, dirt, and environmental factors made this impractical and soon it was decided to enter data in the hotel for that day or in the truck after each inspection.

2. Describe the system?

System gives access to plans and old inspection.

3. How does the laptop interface with other systems? (mainframe, database, PONTIS®, as appropriate)

Through NDOT Intranet so at any NDOT office.

4. How long have you been using it?

Snce1995

5. How widely is the system implemented (geographically and by whom)?

ALL

6. How widely is the system used (geographically and by whom)?

ALL

7. Describe the development process?

Developed SBIS with FHWA and have had three version since the initial version in 1995.

8. What kind of training do you have, how frequently is it offered, what is the duration, who provides it?

SBIS takes a good amount of time to learn to use and is not a user-friendly system.

9. Do you use specialized hardware? If so are there specific models or configurations? Is there anything you would not recommend?

No

10. Describe your software?

NA

11. Do you customized or off the shelf software?

Customized SBIS, looking to switch to a GIS database that is much more user friendly than SBIS.

12. Do you consider the system reliable?

Somewhat

13. How do you maintain and upgrade the system?

NA

14. Do you have any written or electronic material?

None

F.11. New York

Date: 7/18/02

1) How are you using the laptops in the field?

Field people are using many programs to collect data from the field and create true multi-dimensional electronic inspection. System allows inspectors to collect ratings and also ample room for comments. Many attachments such as plans, photos, numerical recordings, maps and etc. An interesting fact of New York style of inspection is that it is based on spans. Each span is individually inspected, as it was a stand-alone bridge. The system is rather sophisticated in the sense that an overall program opens up other programs to view plans and other attachments. Still most inspectors perform the inspection then go to the car and record information onto the laptop. System is called BIPI (BRIDGE INSPECTION PROGRAM - PEN INTERFACE) 12 to 15 files have now been eliminated and placed in BIPI.

2) Describe the system?

The inspector after recording the information sends the file usually via zip file to the Quality Control Engineer. This engineer is responsible to go through the inspection sent to him and check for inconsistency and results he/she is not happy with. If the inspection is found to be satisfactory he signs off on it and sends it to the Central NYDOT office. If the inspection is found to be unsatisfactory they are sent back to the inspector to make corrections. The quality control engineer can also make comments but is limited to not change any ratings. Restricted access is permitted for the QC operations. When the file is received at central they randomly sample some of the files and he/she is able to review these selected files and send them back or accept them just as the QC engineer. After this process the files are uploaded. After this a PDF file is formed for the inspection. The pdf file is available for viewing on the web.

3) How does the laptop interface with other systems? (mainframe, database, PONTIS®, as appropriate)

Data is transferred by email through zip files. Some use CD's and send large numbers of inspections at the same time.

4) How long have you been using it?

Finishing up the 3rd year now. Over 99% of the state is using this system. In the first year region one around the area of Albany used the system. The second year they expanded it to other area and last year they went statewide.

5) How widely is the system implemented (geographically and by whom)?

Statewide, all state inspectors and consultants use the system

6) How widely is the system used (geographically and by whom)?

Statewide, all state inspectors and consultants use the system

7) Describe the development process?

Program not self contained uses WordPerfect, Paint shop pro, Quattro pro

8) What kind of training do you have, how frequently is it offered, what is the duration, who provides it?

The central state DOT and developers hit the road and visited inspectors and consultants and trained on the program. Also large manual available on the web that provides a step-by-step approach to training.

9) Do you use specialized hardware? If so are there specific models or configurations? Is there anything you would not recommend?

NA

10) Describe your software?

The software when open has tab on top that when clicked opens up new pages. Those tabs are Spans, Abutments, Field, Vulnerabilities, Access, Recommendations, and Flag Reports.

11) Do you customized or off the shelf software?

Completely customized software developed in house. The system is powerful and NYDOT is very satisfied with the system. However the system is not easy to install and the learning the software takes some time.

12) Do you consider the system reliable?

Data transfer can be problematic if the protocols for naming and file management are not followed. Another problem is that the file space required for this system is quite large.

13) How do you maintain and upgrade the system?

Program is in a constant state of troubleshooting. It is foreseen to be a program that is continuously upgraded and added to.

14) Do you have any written or electronic material?

Much, http://www.dot.state.ny.us/structures/progeval/bippi/bippi_home.html

Notes: NYDOT has a path (linear) system inspection. They have also implemented a high level of security

F.12. Pennsylvania

Date: Not available

52) How are you using handheld in the field?

Collect inspection data in the field for NBI and BMS.

53) Describe the system?

54) How does the handheld interface with other systems? (mainframe, database, PONTIS®, as appropriate)

The data flow works with a direct flow from the bridge site to the PDA to the mainframe-uploaded mainframe onto the data form.

55) How long have you been using it?

1-year

56) How widely is the system implemented (have equipment and software for using handheld devices) (geographically and by whom)?

About 50 people use this system.

57) How widely is the system used (as in actually make use of the hardware and software) (geographically and by whom)?

About 50 people use this system. Some problems with download not a 100% soon but these problems should be eliminated. Expect to go completely statewide.

58) Describe the development process?

The PDAs were purchased and software was developed by consultants. The field collection software was based off the forms that were used before.

59) What kind of training do you have, how frequently is it offered, what is the duration, who provides it?

The consultants that developed the software put on one-week training classes across the state.

60) Do you use specialized hardware? If so are there specific models or configurations? Is there anything you would not recommend?

Hardware is standard PDA doesn't remember particular type.

61) Describe your software?

Forms reinvented into a digital format.

62) Do you use customized or off the shelf software?

Customized by the consultant.

63) Do you consider the system reliable?

Yes consider the system reliable and a big time saver.

64) How do you maintain and upgrade the system?

New system problem has not arose yet

65) Do you have any written or electronic material?

Literature is available on web page of PennDOT.

F.13. Utah

Date: 7/11/02

1. How are you using the laptops in the field?

They are using the laptop to record NBI and PONTIS® data in the field. The inspectors come in and anywhere from 50-125 bridges are uploaded to the laptop. These usually are in the same county or geographic location. The inspectors usually go out in a group of three with two laptops between them.

2. Describe the system?

He described the program as a PONTIS® type program but I asked him if it was developed in house and he told me yes. There are 115-120 fields beyond the NBI field that are constantly being changed by UDOT

3. How does the laptop interface with other systems? (mainframe, database, PONTIS®, as appropriate)

Laptops are brought in and connected to the mainframe and information is downloaded and uploaded.

4. How long have you been using it?

This particular system has been in use for18 months but before that they were using laptops with a d-base system previously. All in all they been using laptops for 8 years

5. How widely is the system implemented (geographically and by whom)?

All Inspectors are required to use it

6. How widely is the system used (geographically and by whom)?

All Inspectors are required to use it

7. Describe the development process?

D-base system was a little antiquated so they held meetings and developed an idea of what they wanted and continued this and even had some minor training on the new system before they switched over.

8. What kind of training do you have, how frequently is it offered, what is the duration, who provides it?

The training was all in the meetings and maybe was a day in length but not all in one sitting. UDOT provided the training. All other training is in the field through the other inspectors.

9. Do you use specialized hardware? If so are there specific models or configurations? Is there anything you would not recommend?

NO

10. Describe your software?

He described it as PONTIS® version 4.0 with additional fields

11. Do you customized or off the shelf software?

Customized in the sense that they decided what fields to create

12. Do you consider the system reliable?

Very reliable and extreme help

13. How do you maintain and upgrade the system?

NA

14. Do you have any written or electronic material?

Not that he can think of

F.14. Washington

Date: 7/9/02

1. How are you using the laptops in the field?

The inspectors are using the laptops by going out into the field and inspecting and recording that information on to the laptops. They do multiple inspection before returning to the office where the information is download.

2. Describe the system?

NA

3. How does the laptop interface with other systems? (mainframe, database, PONTIS®, as appropriate)

The computer is brought into the office and connected with mainframe.

4. How long have you been using it?

Since 95 but the system has grown in scope

5. How widely is the system implemented (geographically and by whom)?

All over (standard way)

6. How widely is the system used (geographically and by whom)?

All over (standard way)

7. Describe the development process?

The idea for the system was developed out of a need to bring PONTIS® into Washington in 1995. Laptops were initially used and their role has grown to include NBI and digital photos. Now the inspection system has moved towards almost a complete Digital system with plans, *photo, BMS, NBI, and repair information available on laptop. The only paper that the still exists is the inspectors like to take a hard copy of the inspection form and then fill out information from the form onto the laptop in the car. They would like to eliminate this by putting into the hands of the inspectors PDA type devices eliminating paper. Was not really clear that they were moving towards a system that would use field download instead of office download. Automation has increased efficiency. Helps a great deal with planning of inspections and keeping track of progress on repairs.*

8. What kind of training do you have, how frequently is it offered, what is the duration, who provides it?

NA

9. Do you use specialized hardware? If so are there specific models or configurations? Is there anything you would not recommend?

Regular hardware that has been updated.

10. Describe your software?

NA

11. Do you customized or off the shelf software?

Customized software that was developed in house at first but as it has grown in it complication they have brought on private consulting to help out with the programming.

12. Do you consider the system reliable?

Very reliable

13. How do you maintain and upgrade the system?

Continuously developing as needs present themselves; system is added onto.

14. Do you have any written or electronic material?

Is going to send me a PowerPoint presentation of the system.

F.15. Notes from Informal Conversations

Iowa

Interview - August 9, 2002

I called a representative of Iowa DOT regarding the progress of Iowa DOT's research project that was recently awarded to research handheld devices for bridge inspection. Unfortunately he had no idea about this research and was unaware that it even of its existence. He did mention a past research project that Iowa State University worked on a few years ago the. The project developed a software package that worked on a handheld device and also had another part that worked on the desktops back in the office that was used for transferring data. Program though never came out of development and was not used to his recollection. He is sending me a large quantity of documents and reports because of his lack of knowledge about the specifics.

He also began to tell me that Iowa DOT is moving towards electronic records management. This has some ramifications for the bridge inspection procedure as well. Where sketches, photo, and inspection reports and all hard copy material related to bridge inspection are looking to be transferred into a digital format. The goal for bridge inspection reports is to have them available over the Intranet. This has been done for the SINA report, which is the information that the federal government requires. The inspectors now use hard copies then type in report then scan in sketches or add digital photos. Planning to make full implementation that next year. As in Illinois the PONTIS® data is collected but seems to have little use in Iowa too.

Massachusetts

Interview - August 7, 2002

The call was to follow up on a paper reporting experiences at the Massachusetts Highway Department (Leung, 2000). Massachusetts had been using Laptops for inspection since the mid to early 90's. This developed out of a PC database built around 4D.

Massachusetts has 5 districts. There are six units of inspectors: one for each district, and one underwater inspection team. They used ClarisWerks to fill in data. There are 140 fields that are from 4D. The main server in Boston is updated from the laptops.

IBIS is an archival system that allows all this information to be stored. This was set up and license rights were purchased from Trilon. This stores tiff, JPEG, inspection files. IBIS license rights were not bought this last year so this system will not be updated any further. Inspectors don't necessarily use this system except for the areas they are required to do. IBIS doesn't seem to help them that much.

In the future pdf files are to be created from inspection report. Hoping to integrate characteristics of 4D and IBIS and move away from the use of ClarisWerks. In my opinion we should not visit Massachusetts because they seem to be a work in progress with many holes.

APPENDIX G.

FIELD VISIT: MARYLAND

March 21, 2003

G.1. Background

Maryland Department of Transportation is centralized. They like to describe their state as "America in miniature." They have every kind of environment: urban, rural, and suburban; mountains, farmland and ocean; and high growth, and economically depressed.

The bridge section is organized in two areas: bridge design, and remedial engineering. Inspection comes under remedial engineering and most of the engineers are PE's.

Maryland has 2,500 bridges and 3,600 small structures. These are all the state owned bridges except tollway-administered bridges and those owned by the Department of Natural Resources (DNR). The bridge inspectors also inspect noise walls. There are 7 inspection teams geographically distributed over the state. Most inspectors have 10 years experience but are not engineers. The lead inspector is required to have 5 years and participate in the training course. Altogether there are 18 inspectors and 2 snooper operators. The staff has been very stable and committed to their work.

Consultants inspect drawbridges and moveable. They also do underwater water inspections and any specialized inspections such as ultrasonics. Maryland DOT inspects Amtrak bridges every 6 years.

Bridge Inspection

Maryland uses their own inspection forms to code both NBI and PONTIS® data. Inspectors are equipped with

- Phones (originally radio)
- Extended vans (set up their own work areas including a desk and filing system) as shown in Figure 32.
- Inverters
- Printer scanners
- Laptops (mobile office, replaced every 3 years)
- Digital cameras

- Capability to do upload/ downloads at any district offices

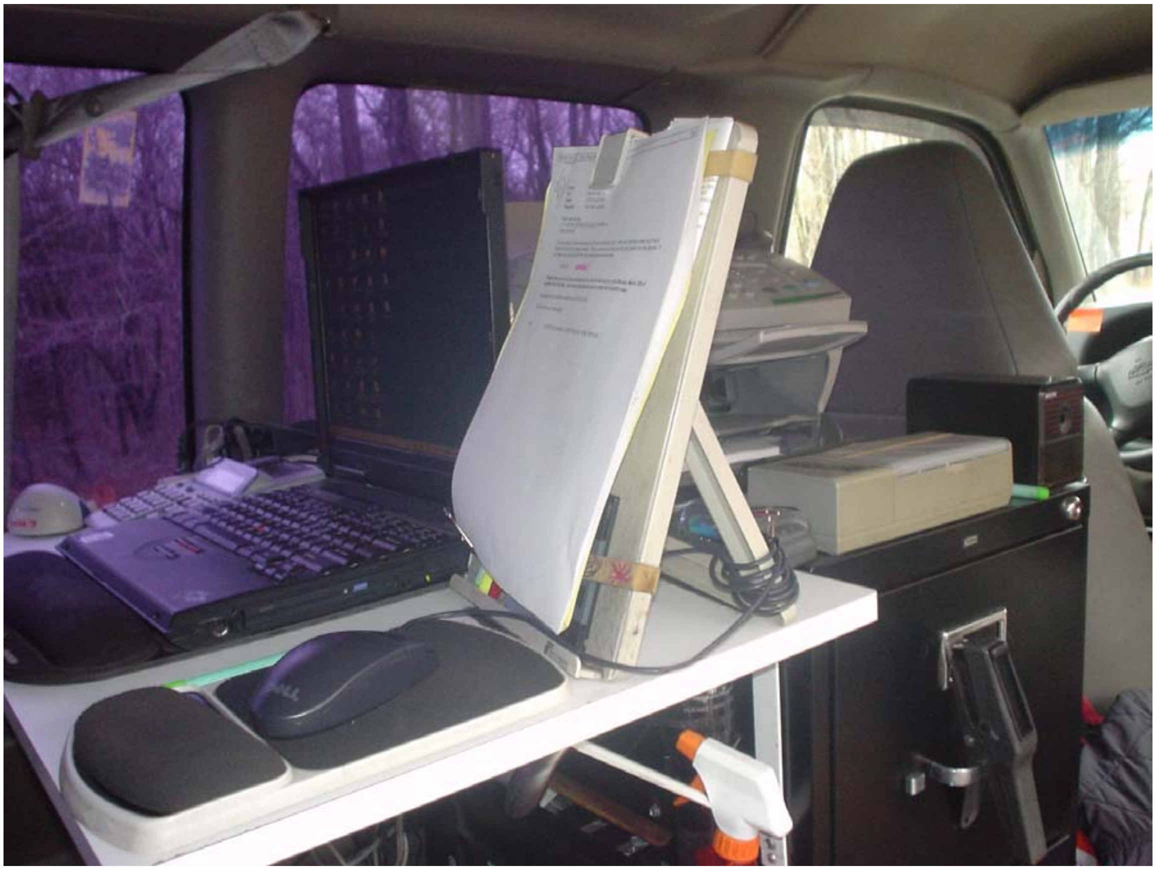

Figure 32. Work Area in Vans Used by Bridge Inspection Crew

If the inspectors find a defect related to structural concern they issue of *screamer report*.

Report goes to engineer with field follow-up. *The type of action depends on the severity of the defect. For example, the construction section has private contractors on broad remedial repairs that are done immediately.* The screamer is also reviewed by the team leader for bridge inspection and remedial engineering and by the senior project team leader to compare it with the current work list. The objective is to complete a field visit within 10 days and make a recommendation within 80 days. Immediate problems are dealt with via cell phone.

Any follow up requiring an engineering inspection produces a hand written inspection form that goes into the file. The inspector can also request action from the district (Item 001) but it is up to the district to prioritize these activities.

Each inspection team has some NDE training but it is not often used. Each crew carries:

- D-meter
- Magnetic particle trained but seldom used.
- Dye penetrant

Laboratory (Materials Section) does NDE as required. Emphasis is on ultrasonics and GPR by contract if needed.

Quality Control

There is some concern that same guys inspect the same bridges every year. Over the past few years, they have not found any immediate issues. Open minds are encouraged and constant training helps to tackle these issues. There is also an audit program that they try to carry out once a year. Five bridges are assigned to every inspection and they compare notes. Teams also meet quarterly to discuss issues. All inspectors for the entire state and engineer at central meet 4 times a year to go over issues and have presentations.

Bridge Inspection Process

Each bridge inspection crew has an assigned territory. They have a list of the bridges coming up for inspection and make their own schedules. Once a month they will assemble the hard copies of the bridges folders for the bridges they are planning to inspection.

Each team has all the bridges on the hard drive for their territory. Plans are digitized. Crew can ask for plans and have them emailed to them.

The inspectors print out the previous inspection form and mark up any changes when they are on the bridge. The inspectors do the data entry in the van, often before they leave the site. One inspector will do the data entry; the other inspector will check it. The data is uploaded at the end of each month.

The electronic files contain complete data back to the 1994/ 1995 inspection cycle. Includes:

- old inspections forms and related inspection,
- elevations,
- soundings

Each element requires a narrative explanation of the rating and changes. Some of the narratives are long. Inspectors will date the material and add on to the existing narrative providing a rich record of observations and explanations.

The end result is an inspection report that is identified by bridge number and inspection date. The report is printed and put in file. The file can also be accessed over the network. For scour critical bridges the files include scanned sketches that appear as thumbnails with photos.

For the past two years Maryland has maintained a digital photo log. The system is fairly simple. The most important feature is the naming convention.

The paper file also includes an Engineer's inspection report and work order for any defects. There are two versions of the paper inspection folder:

- Inspection folder –what inspectors take into field
- Bridge folder – what is in central office

Bridge Management and Decision Making

Maryland does not currently use a formal bridge management program. They attempted to use PONTIS® but the decision-making did not reflect the right priorities. Use of PONTIS® was abandoned two years ago. They had issues with training and thought some aspects were over complicated. They also found that the bridge sufficiency rating does not capture bridges that are in the worst structural condition. Currently the bridge program is assembled through a series of steps:

- The inspectors, districts and remedial engineering section make recommendations. Typically it takes about 5 years to get a bridge replacement and 3 years for a deck replacement.
- Since 1995 a "Tour Program" is used to assemble this information.
- Each year two senior engineers visit all the bridges in the *Tour Program*. This is typically around 250 bridges. These bridges will have a rating of 4 or less for the interstate or 3 or less for other bridges. Prior to the tour an email exchange is used to assemble information and background.
- Bridges on the *tour* are assigned a priority from 1 to 10.

Basic concept is SAFE – **S**tructural **A**dequacy (Items 58, 59 and 60), **F**unctionality (lot of traffic etc) (detour, clearances), and **E**xposure (scour, fracture critical).

They are particularly looking for bridges with low Structural Adequacy numbers, a 4 or below for interstates and 3 or under for non-interstate bridges and what they describe as “white knuckle bridges” (bridges that you feel uncomfortable driving over). They balance the $40m expenditures around the regions. The process is not computerized and relies on the fact that the same two guys provide some consistency. They also use a bridge deck-rating program that prioritizes deck replacement (chloride content, patching etc) through field data and lab.

G.2. Software

Overview

A series of databases and programs provides access to bridge information at the central office level not available at district level. The overall concept is shown in Figure 33. Many of these applications are loosely connected to facilitate the exchange of information. The applications are a mix of Access database, collections of files manipulated by off the shelf software and legacy systems. Systems and data are under control from the bridge section.

Most of the applications have grown out of frustration with existing systems. Bridge staff (generally one person) writes the application, maintains it and does the training for the users. They also monitor the data for QA/QC. This includes checking for duplicate files and consistency. Basic strategy has been to have a crew experiment with the technology and then have the crew share this information at the team meetings. This strategy has been successful with both digital cameras and laptops. The one drawback to this approach is that there is not one place/program to access all the information approach lacks integration.

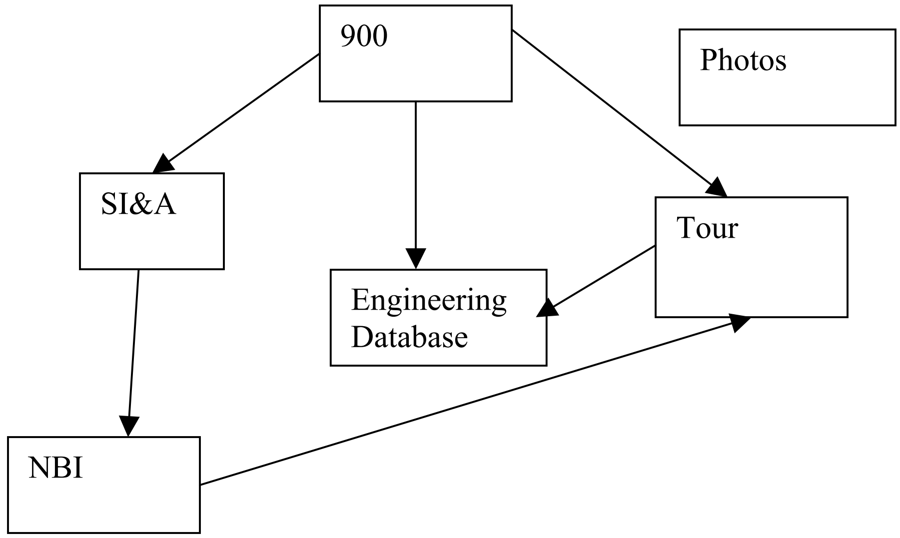

Figure 33. Overview of the Maryland Software Applications.

Each application is briefly reviewed in the following sections.

SIA – Structural Inventory and Analysis

This is an old Informix database. Much of the data was input in the 1970s. That has been ported to Access. It includes the basic data required by the NBIS. Inspectors cannot change the data in the database. Interfacing with other programs is a manual process.

Inspection database

This is the key mechanism for field data collection. It was developed in response to frustration with the PONTIS® interface. It is a fairly simply Access application. The inspection use laptops in their van to run the data. The system was first introduced in 1998. There have been no problems with the laptops. However, they have had some problems with printers.

The application also manipulates data from the inspection report to produce NBI data including running all the error checking programs that FHWA needs.

Engineering database

This is a more elaborate version of the inspection database for office use. In addition this database includes project management and decision-making support. This database can be used to run questions, such as paint in poor condition, or holes or pits in the superstructure. These queries are based around the narratives that are not available in PONTIS® or typical NBI data.

Additional features in the engineering database are:

- Screamer – engineering follow-up –job no (10,000)
- Date – status (active inspection initially) – suspense date
- Engineers follow up – work required and priority (A, B, C, D with A as the highest priority) – active job
- Construction activities
- Weekly priority list with fields that help track projects
    - UC under construction
    - TC to contract
- Also track engineers estimate, final cost

Bridge inspectors also get an FYI when actions occur.

Tour

This is the database of bridges on the *Tour.*

Photos

The photo software is based around a well-defined naming convention as shown in and Figure 35 and off-the-shelf software Hijaak Pro[3] that manipulates photos. Each bridge has a series of identification photos based around the naming convention shown in . When defects are identified, the photos are labeled using the naming convention shown in Figure 35.

[3] HiJaak Pro, v5, International Microcomputer Software, Inc. http://www.imsisoft.com/

Identification Photos

0	**2**	**0**	**7**	**0**	**0**	**0**	**-**	**0**	**6**	**1**	**9**	**0**	**2**	**-**	**I**	**-**	**w**	**p**

Bridge #
7 Characters

Date
6 Characters

I= Identification

Location
Wp=west profile
Lw = looking west
Ep = east profile
Le = looking east
Na = north approach
Sa = south approach

Figure 34. Maryland Photo Naming Conventions for Identification Photos

G.3. ***Lessons Learned and Future Directions***

The current PONTIS® inspection module is better than their in-house version. However, getting the priorities right – to reflect heavy traffic bridges with structural issues as the worst bridges – is a challenge. The fact that Maryland is centralized to such an extent makes comparison to Illinois at the state level difficult but at the district level their experience provides central with what could be some appropriate tools for district level.

Defect Photos

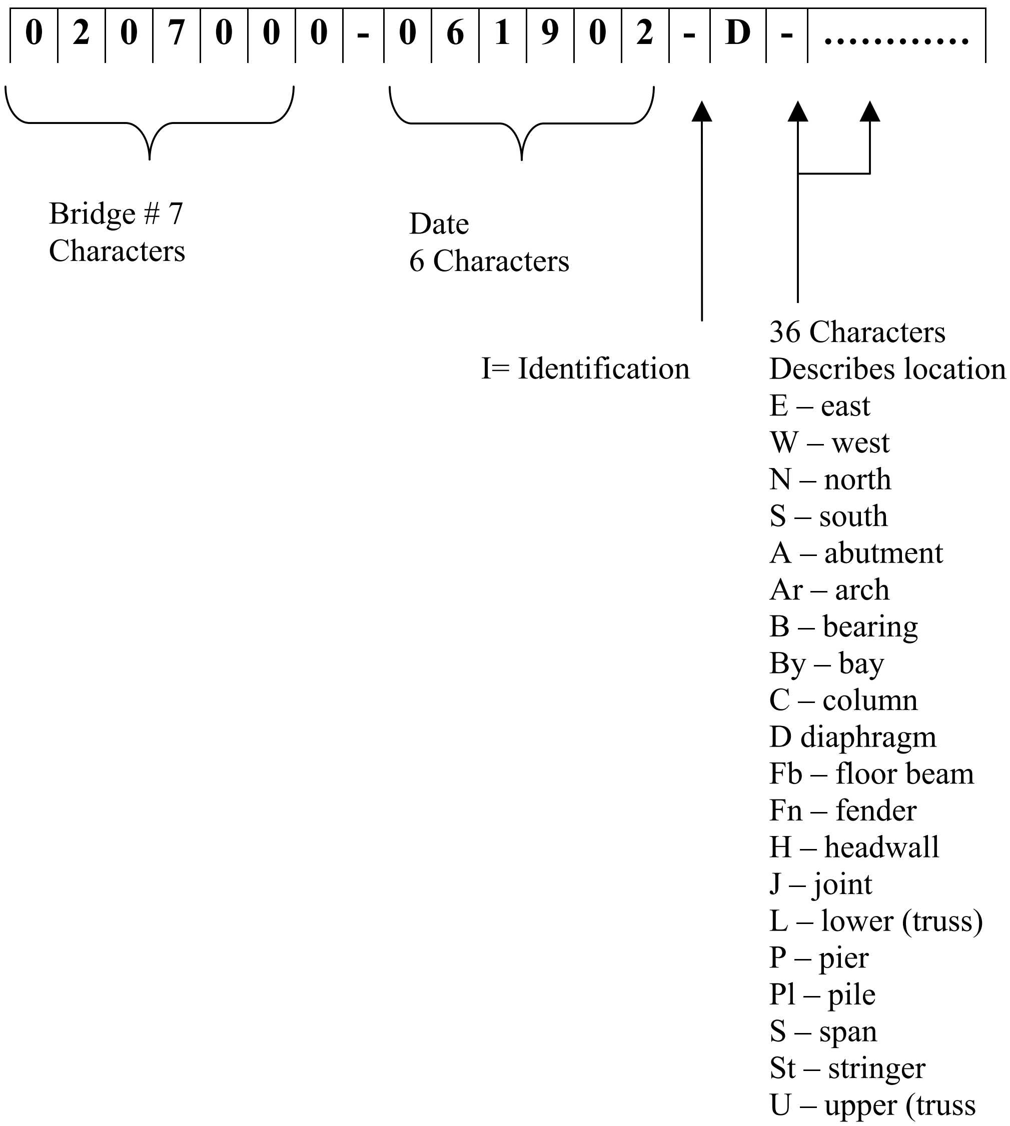

Figure 35. Maryland Photo Naming Conventions for Defect Photos

APPENDIX H.

FIELD VISIT: MONTANA

March 28, 2003

H.1. Background

Montana is subdivided into 7 districts. A district includes an administrator, construction engineer, project managers (these are the bridge inspectors), and maintenance chief. Districts in turn are subdivided into sub districts. There are approximately 30 inspectors, but only two are fulltime who work in the more populace districts. As inspection is a function of construction division, most inspection is done in the winter. All inspectors have computer and network access in the maintenance facilities. Because of the districts size they are further subdivided into section assigned to a particular inspection team, which try to rotate now and then for a different set of eyes.

Bridges lasts a long of time in Montana because of the dry climate. The biggest structural problem is decks but Montana has a lot of functionally obsolete bridges. In total they have inventoried 5,010 bridge and they inspect 4,400 bridges. Of these approximately 2,200 are on system bridges and 2,200 are off system bridges. These bridges include state, county, and local owned. Montana DOT inspects about 2,000 per year. This is because about 600 bridges are on a 48-month cycle (these are prestressed concrete, built after 1970 under contract to DOT, and less than 100 foot span.)

The bridge inspection process is influenced by opportunities for funding bridge improvements. Sources of funding include:

- Federal funding that includes pass through to counties
- Department of Commerce funding that supports bridge improvements for county owned bridges. The program allows counties to nominate bridges that would not necessarily qualify through the federal program. The 56 counties in Montana submit requests to this very competitive on a two-year cycle. The program usually funds replacement of about 20 bridges a year

- TSEP – Treasurers State Endowment Program that allows counties to pick bridges for rebuild or rehab and cost are split 50/50 between state and county. 25 bridges are done every two years.

Basic Concepts

The bridge inspection system is web-based. Therefore access to data is fairly open. Montana DOT has made a commitment to Oracle™ across the department. Training is available for anyone who wants to attend; because of this many in office have some Oracle™ proficiency. The department also supports a photolog system, and a traffic information system. Inspectors have access to these systems at the field locations.

The bridge division as a stand-alone system has built the bridge inspections systems. It is beginning to be used by other division and supported by ISB –Information Systems Bureau.

Project History

Montana initiated bridge inspection in the early 1980's. In 1989 they adopted PONTIS®. In 1995, the systems programmer revised the inspection module with all data entry occurring at the central office. In 1996 a new inspection module was introduced using Oracle™ tools. This module integrated the element level inspections but data entry was still done at the central office. In 1998-1999, inspectors started to enter their own data in field. The Java™ application runs on a Spyglass™ server. However printing became a major problem. In 2002 a revised interface was released more user friendly. This application developed in html/ xml runs on the Spyglass server using Apache. There is no software to distribute and the application is much more stable.

The strengths of the system are that it avoids a lot of the mindless work, facilitates data transfer between applications and makes the data correction process more robust. It also consumes lots of resources for printing.

Bridge Program/ Decision Making

There is no real bridge maintenance program in this state. It is described as a "fixit program."

The concept of preventive maintenance is relative new because of the administrative divisions between bridge engineering and bridge maintenance. However there are real problems tracking cost data. Managers have been asked to document any work on a bridge and the inspector will be contacted once bridge is open to traffic. Inspector has 30-60 days to update the information.

The BMS/ Bridge Maintenance Engineer used bridge codes in bridge management system to defined what work is done but no information is coming from maintenance management system.

Montana has not taken advantage of the decision-making capabilities in PONTIS®. They put together the program by prioritizing using the sufficiency rating (SR.) Now that they have history they believe they need to start using the data to support decision making. Anyone can run queries on the system.

H.2. Bridge Inspection Process

To set up inspections, a query is run on all bridges due for inspection in a county. The paper file is pulled. The inspectors will map out their route. They will try to go to the furthest bridges in the fall. Data is entered in the local offices. Generally the inspectors use a copy of the last inspection form and make notes at the bridges. They then enter only data that has changed. (There is some concern that there should be a "fresh look" at a bridge.)

Local district buys inspectors equipment except for the computer, which is provided by central. Time charged to bridge inspection program. Each of the inspectors has access to and uses the following resources:

- Inspection manual
- Inspection aids
- Road log (information in inspection report for all bridges) - Updated daily at 6am. – pdf file
- Inventory routing

- Load analysis program
- Inspection reports – bridges due for inspection
- Funding report – bridges now eligible for funding

Inspection notes include record of calls or email. Email may not always make it to file. Any changes should be supported with notes. If it is a severe change then the inspector will also send in an email. Each of the inspectors have laptops but they do not general using they in the field.

Three copies of inspection report are file – one for the owner, one for the local files, and one for the files in the main office. Paper files also include photos and correspondence. Montana DOT plans to move from paper to digital photographs but find that they need a server for the photos.

Plans are also currently paper-based. If an inspector needs plans, they can be scanned in central office and emailed to inspectors or put out on a shared drive. More recent plans will be available electronically through the document management system. However, inspection is not part of the document management system and probably does not need to be. The document management system creates a project book. It is aimed at new projects.

Track time spent on bridge.

Load ratings are done in central office using VERTIS and some other internal programs. They are updated if the inspector requests an update via a work item or an email .

Specialized inspections include scour and fracture critical. These are paper-based for now with a notation in the inspection record.

Bridge Inspector Training

Inspectors certified through a 2-week training system. The majority of inspectors are construction technicians, some are engineers, and some are professional engineers. Usually they have some experience with bridge inspection work as an assistant before they do the class. Often the bridge inspectors work alone in Montana.

Each year additional courses are offered. They include the National Highway Institute refresher course, or the fracture critical course. The DOT also brings the inspectors together for a two-day bull session every February to deal with issues that appear. This might include training of new database (as was the case in 2002 as the new database was introduced March 2002.)

Inspector Perspective

Overall the system works well. Some of the minor glitches have been corrected. For example, there was a problem with the printout for bridge rails. Similarly, reports need to follow the same logical order that an inspector follows in conducting the inspection.

Inspectors use most recent inspection forms and note changes. They try to reverse the roles from one inspection to the next. They review the files and forms before going onto the bridge. Typically they will carry the form, something to mark, awl/ putty knife, paper/ pen, pick, and camera. For a metal structure would also carry a magnifying glass, scraper, and wire brush. In their truck they will have a core and other materials. They do the write up in the truck. If there are any immediate problems they will call the bridge owner (cell phone coverage is good.) In general the inspector does data entry and the assistant does a check.

For a typical 3-span bridge with 65 –100 ft spans, an inspector would spend 20 – 30 minutes on bridge and 10-15 minutes taking notes. An inspector will typically inspect 4-5 bridges per day. Data entry is usually done in the office (occasionally in the truck) within a week of the inspection. It takes about 10-15 minutes per bridges unless there are major comments to be made.

H.3. Bridge Management

The bridge management system is starting to include enough good historical information to be useful. The maintenance unit is interested in getting quarterly reports from the BMS to plan their activities; for example, they can look at deck problems, queries have been built for this.

The web-based system mirrors the PONTIS® system. It uses an Oracle™ database. All items are derived from the PONTIS® tables with the additional of a “work item”. Inspectors use the website to make their own bridge inspection schedule. The inspectors only see the bridges in their district. The work item actions includes:

- Element item - done by maintenance
- Flexible item – more than one element or opportunistic (deck – might as well do joints) - maintenance or contract
- Bridge item – rehab, replace, wide – major – contract

Inspector can set priorities – low, medium and high and can add notes to explain the specific rating.

Data includes:

- Ratings
- Sufficiency
- Health Index (This was modified from the approach adopted by California. In adding this, they lost Smart Flags.)

Inspectors, engineers, decision makers can access the data through several avenues:

- SQL
- Query Builder
- MS Query - runs automatically from Excel with parameter

The system features pull down menus, cross checking of data for logic, and validity. There are many fields in the inventory that the inspectors cannot manipulate but the inspectors can edit inspection even once they have “committed” (in this case and edit log is created.) In the case of inventory errors the inspector must send them into to central to have them corrected. As a department Montana is not willing to go to digital only version rather than paper. Inspectors and engineers like to look at old pictures and the effort involved to scan everything is just too great.

H.4. Future directions

The current system is functional and widely used but they are always looking for ways to enhance it. For a bridge, they need to ensure that is a complete history of inspections including photos over time. They are currently backfilling NBIS data from 1980 to 1995. They would also like to add data on costing and be able to run different scenarios that reflect different timelines and provide replace/ repair recommendations.

An interface between PONTIS® and Virtis® will also be available soon to automate bridge rating.

One of the problems in Montana is that inspection is largely done in the winter. Cameras, handhelds and other electronic devices do not work at subzero temperatures. One idea is to think about changing the organizational structure. However, PDA applications are coming.

All applications should be scalable.

Issues

People have been the greatest challenge. The basic mentality is that a computer system is like a set of 3.5 index cards. Some people are not interested in learning anything new. Others are afraid of computers. This requires a change of culture.

Similarly getting maintenance on-board is a challenge. This requires a holistic view of the process and thinking about how to better manage bridges not just improving the worst bridge.

APPENDIX I.

FIELD VISIT: NEW YORK

March 17, 2003

I.1. Background

New York State Department of Transportation (NYDOT) is organized into 11 regions. Their basic organizational structure is decentralized. The Office of Engineering has under it the Structures Design & Construction Division. This Division breaks further down into the Bridge Program and Evaluation Services Bureau where Bridge Inspection is located.

The Commissioner is looking at reorganization of NYSDOT focused around:

- Upstate-downstate
- Trade corridors
- Enterprise
- Communications

Bridge Inspection - Organization

In each region, bridge inspectors work in two-person teams. By state law, the lead inspector is required to be a PE. The assistant is typically a graduate engineer. There are 80 two-person teams and consultants. Most bridges on a two-year inspection cycle except the rated bridges, which are inspected yearly.

Each inspector (consultants and state employees undertake a 4-day training course specifically on the NY State rating system. Inspection responsibility is approximately split between consultants and in house inspectors. Consultants do local bridges and all the bridges in New York City. State forces do all state bridges and some local bridges in more rural areas. Consultants use the same process as the state inspectors. One consultant is using a Tablet PC interface (one of the issues is that the sketches use propriety file information, which means that some of the intelligence is lost.) Consultants are hired on a two-year contract. After two inspections, different inspectors or consultants are used for any bridge to get an independent evaluation.

Bridge Inspection – Ratings

Ratings are made for at least 90 fields on a span-by-span basis. The ratings in general are coded as follows:

- Scale is 1-7, 8 and 9 are used to indicate specific conditions
- 1 –closed
- 7 –new
- 8 does not apply
- 9 unknown
- <5 – deficient

Ratings also include the NBIS ratings as required by FHWA. Specific problems are flagged. To responding to these problems flags go to regional structural engineers' office via cell phone.

Bridge Inspection Process

Typical inspection team will have:

- Digital Camera (removable media)
- Dye Penetrant kit (D-kit)
- Traffic control
- Cell phone
- Hammer
- Paint scraper
- Wire brush
- Ladder
- Mag particle kit
- Ziplock bags (asbestos)
- Ladder
- Scanner
- Inverters
- Printer

Former inspection process: (3-4 months)

- Inspectors assigned to bridges on a yearly basis.
- Inspectors take BIN folder (BIN Folder – includes last three inspection file – kept in regional office.) Everything kept in one location not accessible to people in Albany unless sent file by mail.
- Inspectors use a clean form/ hand write
- QC engineer reviews form
- Rating sheets kept in the bridge inspection office
- Key punch (Double punch for accuracy) to BMS database (Notes, sketches, and photos not captured digitally).

  New inspection process:

- Inspectors assigned to bridges on a yearly basis.
- Inspectors take BIN folder to the field
- Data downloaded via DVD for all regional information to laptops
- Inspectors take paper reports onto the bridge
- Enter data into laptop in truck
- Upload data at maintenance or district offices using a CDRW or occasionally using a network connection.
- QC engineer review files – approximately 5% of reports have a query. QC engineer does field visits as required.
- QC engineer sends inspection to main office (about once a month) as a "submission."
- Pdf file of inspection is created.
- Reviewed at main office by liaisons. This quality assurance involves some field spot check about 10% and field visits. Objective is to visit every team once a year. Regionally quality assurance is also performed but not structured.
- Pseudo key punch process creates a flat file

I.2. Software

Implementation Schedule

System was rolled out statewide April 2002. Region 1 has been using it since 1999. Consultants have been using it in Region 11 since 2001. The Thruway, Port Authority, Bridge

Authority, and MTA are not currently using the system. Plan is to get them onboard soon as only the Thruway sends digital information.

Computer Support Systems

Bridge Management System

New York developed their bridge management in the 1980s. It is currently a flat file that stores at least 90 ratings for every bridge but does not include any comments, sketches or photos. These details are maintained in the paper file. NYSDOT is in the process of moving to an Oracle client server database that should be up and running in August of 2003. The Information Systems Bureau is developing the Oracle system.

The basic input information to the bridge management system comes from WINBOLTS. In the current decision-making condition and vulnerabilities drive the decisions. The objective is to more to a 21st century bridge goal that incorporates measures that reflect safety, preservation, and serviceability goals.

In the current 1985 Bridge Management System work strategies are based on characteristics/ logic. Traffic and condition dominate the decision making process. The current upgrading is because the system outgrew the dBase IV platform. The need to migrate to a new platform was based on a systems analysis that was initiated in 1995 and completed '97. The recommendations were considered to be too expensive to implement.

Currently the bridge program is assembled using a VB worksheet - Bridge Needs Assessment Model. The workshop includes the inventory, computed indices based on condition, vulnerability and current project information. The region uses the worksheet to identify candidate projects that are the passed on to the regional bridge engineers, bridge management engineers, and MPO's. The worksheet provides a basis for consistent decision-making. However, to get the complete work program you need to go back to the old BMS as maintenance is included in the BMS but not worksheet. The Bridge Needs Assessment Model can forecast based on projects and budgets but not based on ratings (some traffic, some primary elements).

Inspection Data Collection

The system has been developed over the last eight years. The objective is to automate the gathering of inspection data and make it accessible throughout the organization.

There are two computer programs that support bridge inspection – BIPPI – Bridge Inspection Program Pen Interface, and WINBOLTS - Windows Version of the Bridge Online Transaction System.

Specialized Information

Most additional information is not electronically records. Flags are used to identify something that needs to be responded to. Responses are defined in terms of engineering instructions documented in the manual.

As data is not necessarily recorded this means that there are lots of holes in the inventory systems. Vulnerabilities address some of these holes. In-depth inspection reports could be included as a pdf but it is currently only stored as paper copy in the BIN file.

BIPPI

Overview

BIPPI is a program developed in-house to the support bridge inspection data entry in the field. The BIPPI interface is shown in Figure 1. Designed to capture 95% to 99% of NYDOT inspected bridges some large structures such as suspension bridges have too much data for BIPPI.

Security

Integrity of the system is critical. Each person accessing the system requires an inspector name and password. Only one inspector can access a record at a time. All changes are recorded in the system including the nature of the change, who made it and when.

Support

NYSDOT provides support through training, online help, tutorials and a help desk. The help is a substantial document that stand-alone and can provide answers to most questions.

BIPPI Training is conducted by a consultant. It is typically a 2 ½ day seminar that walks inspectors through the process with their computers and software. Online material includes tutorials, the BIPPI Users Guide (BUG) (as a PDF file), ScreenCam demos, and Corel presentations.

Typically training sessions included ~20-30 participants. Assume basic knowledge of computer operation. Curriculum covered:

- Basic information for a year
- File operations (unzip files)
- Course objectives
- BIPPI program group
- Where to find help (help file, BUG, Demos, Microsoft Access Technical support database)
- Set up and configuration
- Hands on – each tab in the program / linked objects in related to a rated item (including file types)
- Transfer (submissions numbers, updates – including resubmission)
- Test inspection – start to finish
- Running transfer

  Security program
- Backup

- Q&A (throughout the training session)

Structure

The overall structure of the BIPPI interface is shown in Figure 1. The interface is based on a series of tabbed pages and tiled windows. The tabbed pages follow the basic inspection process and it is intended that the inspector goes through these pages in order, although they will move around the different pages as the inspection involves.

The tabs are as follows:

- GENERAL

This is the initial screen. It includes “notes to the next inspector”, an estimate of the number of hours and equipment required for the inspection, any items requiring special emphasis, and notes for improvements.

- RATINGS

Ratings are color coded “red” or “yellow” on the basis of a series of rules that identify the need for supplemental information. Red indicates that a note and/or photo are required. Yellow indicates that the information is complete. For example, ratings below a five or any time a rating drops two levels (for example, a 7 to a 5) requires a note. Tiled pop up windows include:

- Sketches and tables
- Photos
- Notes and Templates
- Rating history in the form of a graph of ratings since 1983

Notes can be dragged forward from previous inspections, or constructed from a template. You can also search on notes by keywords or find similar bridges.

Inspector can also link in any kind of file that is accessible in software used by NYDOT. For example, an ACCESS file could be included. More typically they are photo files or scanned sketches.

- VULNERABILTIES

Vulnerabilities – bridge safety assurance vulnerabilities – is it applicable? – 6 failure modes - hydraulics, collision, overload, concrete, steel, seismic

Consultant does rating on this bridge

Inspector is asked if anything has changed.

(BSA – included in WINBOLTS)

- GENERAL RECOMMENDATIONS –

This tab includes

- General Recommendation (determines need for interim inspection),
- Calculated rating,
- NBI rating

- FIELD NOTES -

Includes data of inspection etc., weather etc.

- AUXILLIARY FORMS

Includes various forms (as WordPerfect Documents)

- FLAGS

Data is entered here. Includes “create/ edit” function (uses a new flagging system – flag ID number is automatically generated). Can include photos and sketches. Color-coding is as follows:

Red – before next inspection – requirements for repair (no grater than six weeks without action)

Yellow – good for next year – inspection (yearly inspection now required)

Safety – dangerous to someone else

Flagging system not automated, flags are called in.

- CULVERT
- ACCESS

Lists equipment needed for inspection (from inventory). For complicated bridges this is not sufficient. Information can be supplemented with information in the general tab.

- ERRORS

Analysis of data and tests (missing data, unusual conditions) – goal is to have an "empty page". Every time a piece of data is entered, an error analysis is completed and this page is updated immediately. QC engineer probably looks at this page first to check for completion.

- CLOSE INSPECTIONS

This tab provides for sign off (this is the only time the signature box is available). The result is a check value number.

- COMPARE

This allows comparison of the inspection with last inspection. Allows the inspector to identify which fields had notes.

- Signature Page

Page available at end of BIPPI where inspector electronically signs file and completes inspection process.

Functionality

The objective of the system is to make the inspector's job easier. For examples, ratings are color-coded.

Technical Details

Windows functionalities are preserved –spell checker, cut and paste, file save etc.

The system is coded in Delphi an Object Oriented Pascal-like programming language. A consultant provides support in a helpdesk-like capacity. With upcoming retirements, the consultant will also now maintain the system. Field personal interact with the consultant via telephone (if urgent), and email (for general questions). Overall, there are more emails than phone calls. There is an open approach to dealing with inspectors willing to add things and make changes to BIPPI based on feedback. There is a key word search for notes that is handy in identify items.

WINBOLTS

This software links inspection information to Inventory – NYSDOT – Bridge Inventory and Inspection system. Includes standard photos, and location maps (produced by GIS group). It is Internet accessible or available from DVD.

Information includes: Identification, structural details, safety, inspection responsibility, posting, feature carried, feature crossed. Also provides access to prior inspections. The last inspection is available as a pdf that includes photos, and sketches that are scanned in. This PDF file is intended to be maintained electronically. It also, includes word-perfect documents. There are prestored documents or the inspector can create their own forms. Includes process documentation (Review Progress and Personnel).

If field verification indicates changes in the data then an edit record of changes is created. It includes pull down menus and record of who/ date/ time.

System also provides:

- Choice of Metric and English units
- Link to GIS – ArcView GIS 3.3
- Without GIS – there are two maps under photos with no capabilities
- Access to aerial photos (when network access is available)
- Elevations
- Standard naming convention for photos based year, and direction
- Simple query tool

Flow of information is as follows:

Field input => quality control => bridge inspection office

WINBOLTS will be redone when BIPPI is redone. Needs to talk to Oracle database. A desire to make drawings available of bridges is something they would like to ultimately add to BIPPI. Inventory Errors have ability to fix them in edit record. Inspector can only recommend changes the authority rest in Albany to fix these.

TRANSFER3

Software for uploading data – creates a package to go to QC. Allows user to choose email OR other means to send it.

PDF inspection file – created by liaison engineer in main office. It is a one-button report that is then sent to the bridge owner via CD, and given to inspectors on DVD/ CD yearly.

I.3. Lessons Learned

Some of the lessons learned by NYSDOT are fairly obvious given advances in software. Others are a little subtler.

- Stay away from WordPerfect. More generally, if you need to do a text processing use a more generic text-processing program

- Could not do this internally in-house now due the recognition of the importance of data integrity. This project started in 1995-96. The aim was to cover most of the bridges, not the special case.
- Need to schedule hardware and software upgrades. This will always be a challenge. Laptops are on a 3-year schedule. Need to create a schedule for digital cameras too.
- Basically, the bridge inspectors like the system. Although this has shifted more of the clerical tasks to the engineers, inspectors get to see the complete process. The recommendation is that the inspector finishes EVERYTHING when they are on the bridge.

  This includes knowing that the photos are okay.

I.4. Future directions

The aim is to have a bridge information center because BIN folders are in the regional office. What is currently missing from the electronic record are plans and correspondence. A study is currently underway to decide the future of the bridge management system. Going to PONTIS® is a possibility. The current BMS includes history, and data to address needs. The real question is can NYSDOT use PONTIS® and convert data? The existing BMS has no prediction tools. Ideally NYSDOT want a work generator that they can put on the web.

There has also been some consideration of using a PDA in the field that might provide a checklist that would help the inspectors to identify anything they have missed in the field.

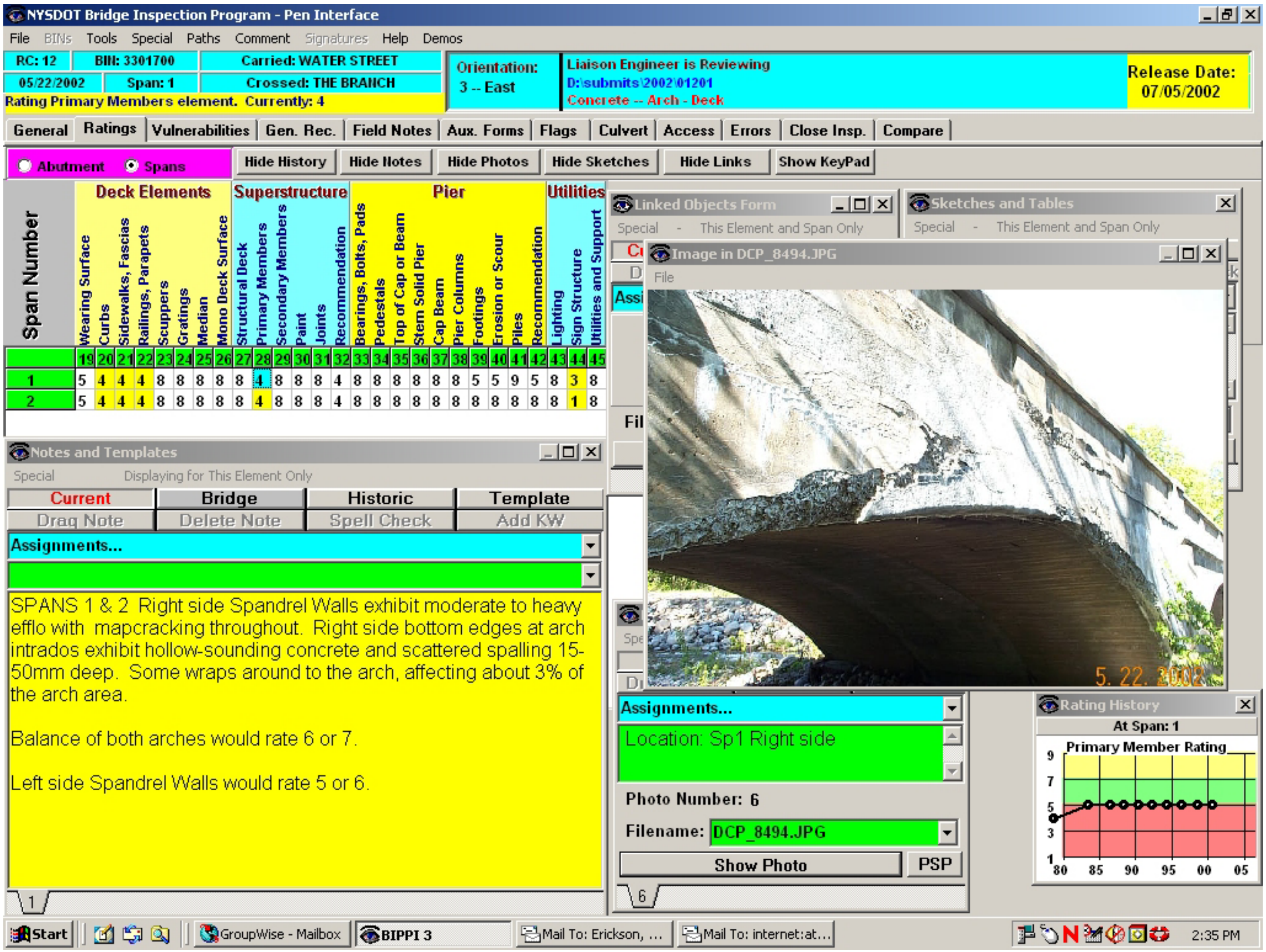

Figure 36. BIPPI Interface

APPENDIX J.

FIELD VISIT PENNSYLVANIA

March 19, 2003

J.1. Background

Pennsylvania is organized around 11 districts. They inspection around 20,000 bridges a year. There are 25,000 state bridges greater than 8ft in length. There are 7,000 locally owned bridges with over 1500 different owners. Over half the bridges are relatively short, less than 40 feet in length.

J.2. Bridge Inspection – Process

Pennsylvania collects NBI data and around 100 additional Pennsylvania specific items. The inspectors provide text to support the ratings. After the first inspection, the inspectors can edit the existing text but need to make sure text and ratings are consistent.

Bridge inspectors work in 2-man teams. Bridge inspectors are trained based on the NBIS requirements including a refresher training course (3 days) every two years. Most of the inspectors are technicians (for example, bridge design technician, or construction inspection series). Inspectors carry the usual equipment in vans that include computer connections and printers as shown in Figure 37.

J.3. Bridge Inspection – Support Systems

Objective is to enter data only once. The end result is a more efficient bridge inspection process resulting in savings in time for the inspectors and improved data quality. With a two man teams and 20,000 bridges inspected every year, saving 30 minutes per bridge is a saving of 11,000 man-hours per year. The support system used Electronic Data Collectors (EDCs) and is built around some basic principles:

- It is critical to do no harm to existing BMS because the system is used for many other things.
- No incomplete records/ no improperly coded records should be included.
- Absolute congruence is required between data in EDCs and the BMS.
- The BMS is the "real" record.

Figure 37. Pennsylvania's Bridge Inspection Vans

- Data collection had to be user friendly – bulletproof and goof-proof, and processes have to be transparent to the users.
- Bridge has to be already in the BMS. No new bridges are added in the inspection system. It is simply a bridge inspection support system. Inventory information is intended to make sure inspectors are on the right bridge. Does not include photos or sketches. The use of digital photos varies from district to district. Also the media varies significantly. This is hurdle that they have not gotten over yet.

The other objective was to design a system for the inspectors. The system needed state of the art equipment so the inspectors were involved in the equipment selection.

It was also critical to build on the narrative part of the inspection report. The inspectors needed to be comfortable with it.

History

The BMS is in an IMS hierarchical database. It was originally operated in the districts on dedicated lines. It now runs over the WAN/ LAN in central office. Dummy terminals are used at the Department of Conservation and Natural Resources (DCNR), the 11 districts and the turnpike.

The inspection support system began as a project of bridge division rather than getting involved with the division of information services. This may have been a poor decision in the long run but was the only way to get a functional product fast.

Software

The development of the inspection support software, referred to as **E-Forms,** began 5-6 years ago. E-forms have been in use for 3 years. E-forms run on a field data collection system referred to as the EDC (electronic data collector) and on a dedicated PC in the district office referred to as the IDB (information database). Consultants do not use the dedicated PC.

Original development was in ACCESS 97. Baker Engineering did the initial development. The objective was to provide software that does what an inspector wants. That is, the software captures all work done in field In early stages data synchronization was done with zip disk but developed to network system.

Each inspector has EVERY bridge in the data collector (especially critical if there is a an emergency). Therefore the inspectors need to synchronize regularly. E-forms are structured to reproduce printed forms. Prior to the development of E-Forms the printed forms were restructured to capture a top-down inspection and capture about half of page of each inspection on a screen in a logical fashion. There are about 10-12 pages of forms including a maintenance activity sheet depending on the type of bridge. E-forms selects which forms are needed. The end result is that the field report is betting written as the inspection is being done. For instance if a waterway is present at the bridge site the appropriate waterway fields appear in E-forms.

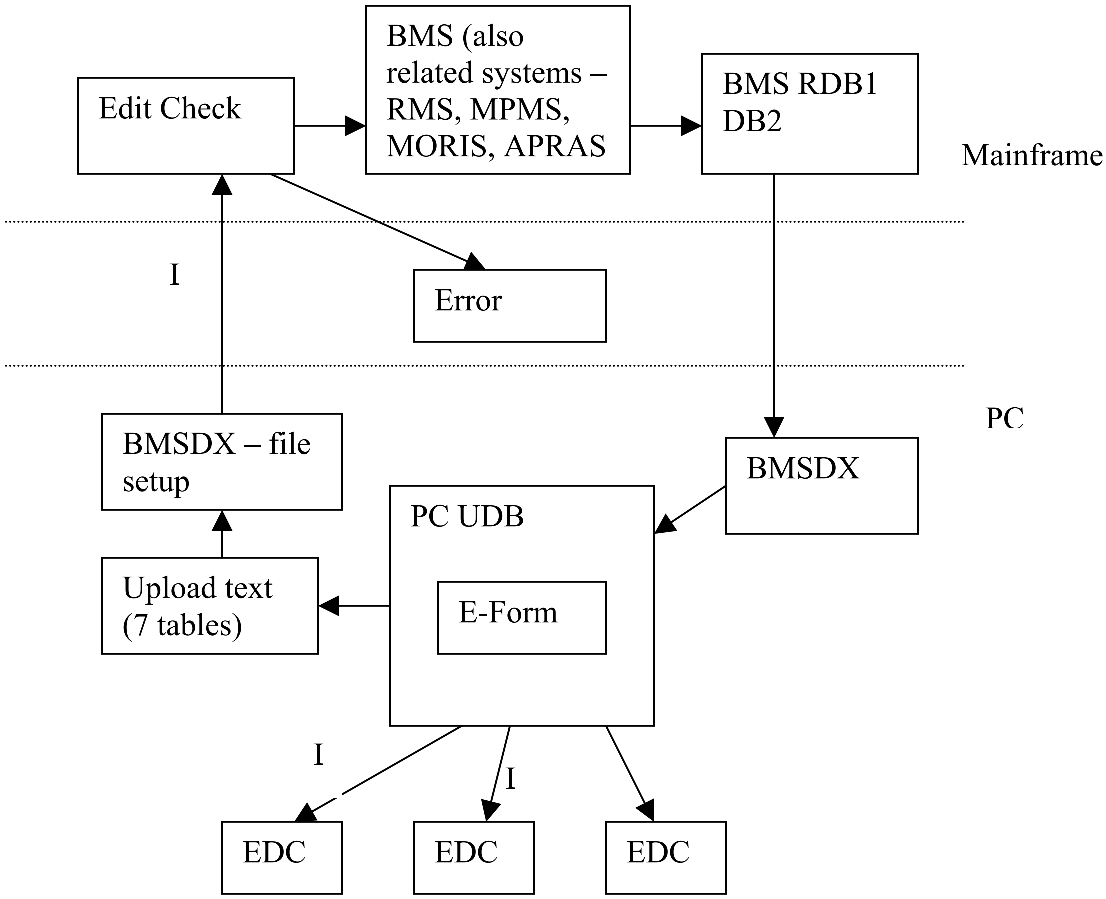

Figure 38. Overview of Process

A program referred to as BMSDX (BMS Data Exchange) is more recent and provides an automated uploading process to the mainframe BMS. The IDB – EDC exchange is very functional, but the BMSDX is more challenging.

Figure 38 provides an overview of the process.

Quality control measures required a physical check through a variable known as "report status" (only happens on the IDB). This variable can take on the following values:

- BMSF - the data (cannot be edited)
- NEW – copy of BMSMF (new record in EDC) (Cannot only be edited in EDC)
- EDIT - When inspection is done – change to EDIT status – can only edited on the IDB
- FINAL - Bridge inspection supervisor changes it to FINAL; the data then goes to upload process (overnight)
- ERROR - If ERROR status occurs then the form can be changed and the status becomes a FINAL and resubmitted.
- PREV - Old BMSMP becomes a PREV (previous) if a new record comes down. This version of the form cannot be edited. Can have multiple versions of these to maintain history.
- ARCHIV - if the bridge has been removed.

Key indices (used to manage the data) are:

- BMSREF
- INSPECT DATE (E06)
- STATUS

Data control is very important to maintain data quality, ensure the integrity of the database and track versions of the records. The data control process needs to be simple and transparent for the inspectors. Assumption is that inspectors are not computer guys.

The paper copy is the official record; therefore, the inspectors needed the capability to print the forms. It is also important to distinguish between BMS data and narrative data. Narratives (explanations) are on the IDB and EDC, but not in the BMS.

The use of past reports during the inspection varies from district to district. Ideally a “track changes” feature (like in word processing software) can be use to make things easier for inspectors but not necessarily make them lazier.

To support the inspectors, the system uses lots of pull down menus. At this point hand-writing recognition is not good enough. The original idea was to use the system data entry in the field using the stylus but few inspectors do this. Unfortunately, most of the narrative entry is done in the truck.

Hardware Selection

Lots of consideration was given to the choice of a laptop for data entry. PennDOT wanted inspectors to have the data collector in their hands in the field so that data entry was in real time. Synchronization was an issue if the process was going to work. Maintenance and district offices have the connections to get the data uploaded.

The final selection was a Fijutsu Pen Based Tablet. The equipment is robust and high speed. Each unit has an IP address and runs Windows 2000 and Office 2000. The docking station is required for Internet connections to synchronize the data. The docking station is also used in the van to provide access to printers. The vans also include workbenches, and filing drawers. The cost for the data acquisition unit was about $5,000 per inspection unit including zip drives, case, extra stylus etc. There are 28 permanent inspection teams plus an extra unit per district and three units in the main office. There are a total of 50 full time inspectors (others are part time.) Although the hardware is rugged, 4 districts have dropped them. Fijitsu has provided a 4-day turnaround as part of the maintenance contract. The districts are responsible for maintaining the hardware.

The inspectors were involved in the hardware selection process. Cybernaut also demonstrated their wearable computers. There was some concern that wearing the device is an encumbrance for personal safety. Screen size is very limited for data entry. It is adequate for checking boxes but it was important to have a mechanism for including the narrative. Voice recognition was VERY clunky.

IBD hardware was not completely in place until about a year ago. LAN and Desktops were already in place. EDC came out of the bureau of design. Districts have to maintain these units and the bureau of design maintains the software.

Training

Idea was to not have a lot of training. Training included how to locate bridge in the system, how to create new inspections, how to finalize records etc. Basically covered in a one-day informal training session when inspectors were given equipment and software.

Where to next?

PennDOT has an upcoming BMS rewrite. This will ultimately lead to the Phase II system requirements. The idea is to include access to any document related to a bridge. It will be part of an EDMS – electronic document management system. Eventually the new BMS will include narrative data. It is also important to add a tabular comparison from this inspection to the last.

There is also a technical issue with the current version of the system. Access generates about 1.5Mb of metadata each time new data is entered. Ultimately this is going to create problems. Currently the system for District 9 represents 5361 records. This translates to 60-70 Mb of data.

QA/ QC process

The quality control process is carefully documented in the BMS coding manual. The focus is on how to put the data in, and the review of reports as they come in from field (although the process does vary from district to district). The inspection supervisor reviews all reports. Once data has been entered in the BMS online, inspectors are not allowed to change certain fields.

There are some very specific quality control checks. For example, bridges that require posting, that is the inventory rating is less than the legal load limit. Penn DOT also conducts several blind inspections using a consultant. This covers around 350 bridge inspections per year. The objective is that the two inspections differ by less than +/- 1. The program would typically cover 30 inspection items for 15 state and 15 local bridges in each district every year. Table 22 summarizes the results for the proportion of bridges within tolerance in 1990 and 2003. Overall the program seems to be effective.

Table 22. Bridge Inspection Quality Control.

Year	1990	2003
State	92%	98%
Local	80%	92%
Cost	\$0.5 m	\$1m

Quality control is closely link to bridge inspection training as shown in Figure 39.

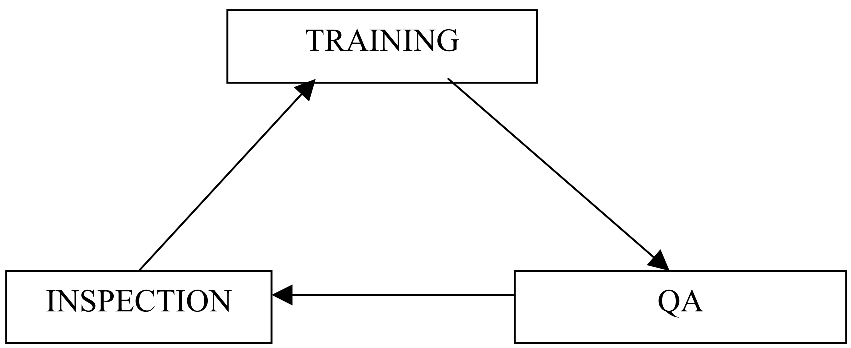

Figure 39. QA/ Inspection/ Training Relationship

Accessing the Data

There are 25 databases

- 11 district (state)
- 11 district (local)
- PTC
- DCNR
- MISC

Each unit must have the same version of the software. Districts are not allowed to work on the database to ensure data integrity. Unfortunately, this means that they have been locked out of their data. However, if they know something about ACCESS they can run simple queries:

- Give me all the bridges with a “3” for paint?
- Do the narratives support this?
- What kind of equipment do we need?
- What have I done in the last three months?

E-Forms Structure

Software must reside on the C: drive with folder nomenclature specific to each district. The basic files structure is set up as part of the programming of the system. The system also provides access to general support information so the bridge inspectors do not have to consult the manual.

The ACCESS database consists of

- Tables
- Queries
- Forms
- Reports

Functionality differs between the IDB and the EDC. The follow sections summarize the functions of each.

IDB

Utilities

Synchronize (have to chose which data collection)

Upload/ Downloads

Create Replicas (full/ partial)

Errors (if relevant)

Bridge Selection Manager

choose a particular record=> BMSF/ PREV

EDC

Utilities

Synchronize

Bridge selection Manager

Select bridge (information + needed forms)

General Screen (information about bridge – is this the one you want)

Report Mode (provides screen for deciding what you want to report)

Back to selection management

Start a new Inspection or edit

Creates a NEW

Enter a from

Graffiti

Pen based keyboard

Keyboard

Open Notes from BMSF Record

Cancel Inspection

The bridge inspector supervisor can access the upload function. This moves the data from IDB to the BMS.

The table structure in IDB is similar to the table structure (screens) in BMS (with the addition of the narrative data). Table 23 shows the relationship between the BMS screens and the IDB tables. To fully utilize the system you need to know inspection process and databases.

Table 23. Relationship Between BMS Screens and IDB Tables

Name	BMS Screens (p1)	IDB tables
General	A	AB
Intro	B	
Structural	C	C
Hydraulic/ Posting	D	
Inspection Process	E	3 screens
……	……	…..
Underwater	W	3 forms

Comments from Penn DOT

The following comments from Penn DOT staff provide some insight into the success of the system:

- The system is currently right at the limit that you can do with Microsoft Access
- When the field folks complain then they say, "go back to the paper form" and they all say they don't want to do it.
- Penn DOT has a key help person; essentially, he provides a help desk.
- Initial development was based on a broad base of experience with bridge inspection. This was critical to capture the inspectors' needs.
- The motivation is based on a commitment to use bridge data to support allocation of funding.
- There is a broad range of experiences. For example:
    - District 3 – Motorsville. – bridge management system
    - District 8 - Gettysburg – field inspection experience.
    - District 9 – Hollidaysburg - used the most

J.4. Future directions

Electronic Data Management System (EDMS)

An EDMS is under development.

Non-destructive testing

Non-destructive testing is used when a weakness is identified or for specialized situations such as fracture critical bridges. The actual testing is very specific to an individual structure. Therefore, there is no good way to report and record the data at this point. Also, Penn DOT is not undertaking any long term monitoring. It would be good to capture this information electronically but may be more suited to capture through EDMS – e.g. linking a document. Also, could be included in the narrative. Can use "see attached sheet" to add more information.

Web enabled

Interesting idea but probably presents security issues.

Wireless

Also an interesting approach, but in general there is no need to enter data to the main systems in real time. The data needs to go through quality assurance process anyway. In Pennsylvania bridge inspection data is excluded from public disclosure.