

Iowa DOT Bridge Asset Management Using Pontis: Data Integration, Performance, and Decision Support Tools



Final Report September 2008

Sponsored by

University Transportation Centers Program,
U.S. Department of Transportation
(MTC Project 2002-02)



IOWA STATE
UNIVERSITY

About the MTC

The mission of the University Transportation Centers (UTC) program is to advance U.S. technology and expertise in the many disciplines comprising transportation through the mechanisms of education, research, and technology transfer at university-based centers of excellence. The Midwest Transportation Consortium (MTC) is the UTC program regional center for Iowa, Kansas, Missouri, and Nebraska. Iowa State University, through its Center for Transportation Research and Education (CTRE), is the MTC's lead institution.

Disclaimer Notice

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the sponsors.

The sponsors assume no liability for the contents or use of the information contained in this document. This report does not constitute a standard, specification, or regulation.

The sponsors do not endorse products or manufacturers. Trademarks or manufacturers' names appear in this report only because they are considered essential to the objective of the document.

Non-discrimination Statement

Iowa State University does not discriminate on the basis of race, color, age, religion, national origin, sexual orientation, gender identity, sex, marital status, disability, or status as a U.S. veteran. Inquiries can be directed to the Director of Equal Opportunity and Diversity, (515) 294-7612.

Technical Report Documentation Page

1. Report No. MTC Project 2002-02		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Iowa DOT Bridge Asset Management Using Pontis: Data Integration, Performance, and Decision Support Tools				5. Report Date September 2008	
				6. Performing Organization Code	
7. Author(s) Omar Smadi, Patrick Stein, Krishna Kallam				8. Performing Organization Report No.	
9. Performing Organization Name and Address Midwest Transportation Consortium 2711 South Loop Drive, Suite 4700 Ames, IA 50010-8664				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No.	
12. Sponsoring Organization Name and Address U.S. Department of Transportation Research and Special Programs Administration 400 7th Street SW Washington, DC 20590-0001				13. Type of Report and Period Covered Final Report	
				14. Sponsoring Agency Code	
15. Supplementary Notes Visit www.ctre.iastate.edu for color PDF files of this and other research reports.					
16. Abstract <p>The Iowa DOT currently owns and maintains over 4,000 bridges and culverts on the state highway system. With heightened concern for the condition of these aging structures, methods for assessing and maintaining the structural performance of in-service bridges have become vital to the preservation of Iowa's bridge network.</p> <p>An economical data acquisition system that is portable and can be efficiently used on bridge structures could supplement visual inspections with field-measured values. By pursuing simplicity in the system interface and installation, tests could be completed by persons with limited engineering background. This concept can prevent bridges from being replaced that are thought to be structurally deficient and help estimate bridge condition in the database.</p> <p>This report summarizes a research project for the Iowa Department of Transportation (Iowa DOT) to develop, implement, and operate an integrated bridge asset management system for the state of Iowa. The system is Pontis, first developed in 1989 and currently used by around 45 transportation agencies, both in the United States and internationally. This system will enable the Iowa DOT to make objective, cost-effective, and timely decisions regarding bridge maintenance, rehabilitation, and replacement.</p>					
17. Key Words asset management—bridge inspection—data collection inventory—decision support				18. Distribution Statement No restrictions.	
19. Security Classification (of this report) Unclassified.		20. Security Classification (of this page) Unclassified.		21. No. of Pages 71	22. Price NA

IOWA DOT BRIDGE ASSET MANAGEMENT USING PONTIS: DATA INTEGRATION, PERFORMANCE, AND DECISION SUPPORT TOOLS

**Final Report
September 2008**

Principal Investigator

Omar Smadi

Research Scientist, Professor of Transportation Engineering
Center for Transportation Research and Education, Iowa State University

Co-Principal Investigators

Brent Phares

Associate Director, Bridge Engineering Center
Center for Transportation Research and Education, Iowa State University

Fouad Fanous

Professor

Department of Civil, Construction, and Environmental Engineering, Iowa State University

Research Assistants

Patrick Stein, Krishna Kallam

Authors

Omar Smadi, Patrick Stein, Krishna Kallam

Preparation of this report was financed in part
through funds provided by the U.S. Department of Transportation
through the Midwest Transportation Consortium,
Project 2002-02.

Project administered by
Midwest Transportation Consortium
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103
Fax: 515-294-0467
www.ctre.iastate.edu/mtc

TABLE OF CONTENTS

ACKNOWLEDGMENTS	VII
INTRODUCTION	1
Project Scope	1
Problem Statement	1
PONTIS.....	2
RESEARCH AREAS FOR IMPLEMENTING PONTIS	3
Collection and Integration of Bridge Structural Performance Data	3
Development of a Computerized System to Capture Bridge Inspection Data	3
Use of Pontis Bridge Management Software to Develop an IBAMS.....	4
APPENDIX A. UTILIZATION OF HANDHELD FIELD TESTING SYSTEM FOR IMPROVEMENT OF BRIDGE LOAD RATING VALUES IN PONTIS	A-1
APPENDIX B. PDA BASED BRIDGE INSPECTION FOR PONTIS BRIDGE MANAGEMENT SYSTEM.....	B-1
APPENDIX C. IMPLEMENTATION AND CUSTOMIZATION OF PONTIS FOR THE IOWA DEPARTMENT OF TRANSPORTATION	C-1

ACKNOWLEDGMENTS

The authors would like to thank the Iowa Department of Transportation and the Midwest Transportation Consortium for sponsoring this research.

INTRODUCTION

Project Scope

This report summarizes a research project for the Iowa Department of Transportation (Iowa DOT) to develop, implement, and operate an integrated bridge asset management system (IBAMS) for the state of Iowa. The system is Pontis, first developed in 1989 and currently used by around 45 transportation agencies, both in the United States and internationally. This system will enable the Iowa DOT to make objective, cost-effective, and timely decisions regarding bridge maintenance, rehabilitation, and replacement.

Problem Statement

The Iowa DOT currently owns and maintains over 4,000 bridges and culverts on the state highway system. With heightened concern for the condition of these aging structures, methods for assessing and maintaining the structural performance of in-service bridges have become vital to the preservation of Iowa's bridge network.

The traditional approach has been for transportation agencies to allocate maximum funds to bridges in critical condition, diverting resources from routine maintenance. This approach almost always results in the gradual system-wide deterioration of bridge conditions. A bridge management system (BMS) is therefore needed to provide a logical approach for allocating bridge funds in ways that improve conditions on the network level, rather than simply at the bridge level. A BMS emphasizes preventive bridge maintenance, i.e., maintaining bridges before they become unsafe, over deferred maintenance.

A BMS relies heavily on visual inspection to assess the condition of bridge structures. However, researchers have noted shortcomings of visual inspections. For example, visual inspections do not permit accurate evaluation of bridge serviceability and safety. Ultimately, although continual visual inspection of bridges is required for a BMS to succeed, these inspections provide limited information about the performance and the capacity of bridge structures.

In contrast, field measurements can estimate various structural properties, such as load distribution, support conditions, and unintended composite action. These tests are non-destructive, relying on strain transducers for their data. Additionally, the structural benefits of various maintenance techniques can be assessed by regularly testing in-service bridges.

An economical data acquisition system that is portable and can be efficiently used on bridge structures could supplement visual inspections with field-measured values. By pursuing simplicity in the system interface and installation, tests could be completed by persons with limited engineering background. This system can prevent the unnecessary replacement of bridges that are structurally sound but that are thought to be structurally deficient, and this system can help estimate bridge condition in the database.

PONTIS

Pontis is a BMS used by many transportation agencies for managing inspections, budgets, and project development for bridge assets. The system was first developed by Cambridge Systematics in 1989 and later expanded to meet the increasingly complex asset management demands of transportation agencies through partnership with the American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), and state departments of transportation (DOTs). Pontis is currently licensed by AASHTO to around 45 state DOTs and other agencies nationally and internationally.

Accurate bridge inspection data are essential to ensure that bridge management decisions, based on the analysis of the database system, correctly reflect actual bridge conditions. Rigorous quality control that does not compromise the speed of data collection is a crucial feature of any data collection system.

In Pontis, a structure (bridge, culvert, tunnel, etc.) is divided into individual component types called elements. Each element has a predefined set of condition states, ranging from three to five. For example, a “deck” element is defined as having five condition states, and an “unpainted steel open girder” is defined as having four. A condition state of an element is defined by the extent of damage or deterioration of that element. For example, the condition states for the “deck” element are defined as follows:

- Condition state 1. Element shows little or no deterioration
- Condition state 2. Combined distress area of element < 2% of deck area
- Condition state 3. Distress area between 2% and 10%
- Condition state 4. Distress area between 10% and 25%
- Condition state 5. Distress area > 25%

A bridge inspector conducting a Pontis-based element inspection must assign the total quantity of elements into one or more of these condition states and record the data accordingly. An inspector must be able to record data in percentages or quantities. For example, an inspector must be able to record that, for bridge ID 3410 and element 12 (the “deck” element), x% of the element lies in condition state 1, y% in condition state 2, and so on. The total percentage for each element must be 100. Additional data to be collected include the total element quantities, if changed from the previous inspection, any new elements added to the bridge, and notes for each element. Any data collection tool should allow a bridge inspector to easily collect all necessary bridge data.

The software on which Pontis operates currently uses a transition probability model to estimate deterioration in different bridge elements. Combined with biannual visual inspections, Pontis uses mathematical methods to assess the performance of bridges, and the system then allocates available funds accordingly. A consistent goal with Pontis is to improve the performance assessment of bridges, thereby preventing rehabilitation and replacement of bridges that have sufficient strength.

RESEARCH AREAS FOR IMPLEMENTING PONTIS

The project of developing, implementing, and operating Pontis in the state of Iowa addresses three research areas:

1. Collection and integration of bridge structural performance data using strain gauges and basic data acquisition devices
2. Development of a computerized system to capture bridge inspection data
3. Use of Pontis bridge management software to integrate the data for the purpose of developing an IBAMS

Collection and Integration of Bridge Structural Performance Data

This research developed a field testing system that would help Pontis select suitable bridge candidates for repair or replacement. This field testing system consisted of a handheld personal digital assistant (PDA) for portable data recording, bridge strain gauges to measure bridges' load capacities, and a signal conditioning unit to process the information produced by the strain gauges. Developing this system involved researching the available hardware and software, programming the PDA to accurately record test data, testing and verifying the system's accuracy and usability, and outlining a methodology for assessing structural performance. A report for this project is included in Appendix A.

The PDA selected was the Hewlett Packard iPAQ h5150, which was compatible with the selected signal conditioning unit and had adequate memory and sufficient processing power for field testing. This device also included an expansion pack that provided extended battery life, which was deemed necessary for field testing. The signal conditioning unit was from National Instruments and featured 16 channels of data acquisition from the strain gauges. Data transfer between the signal conditioning unit and the PDA was through a PCMCIA card, typically used in laptop computers. The strain gauges used in the field testing were Bridge Diagnostics Incorporated (BDI) full-bridge strain transducers. Because these gauges were simple to install and were reusable, state agencies could use them for economical field testing.

During testing, the PDA was primarily used as a storage device, with little data manipulation capability due to the device's limited driver functions. However, recently developed drivers for handheld programming are evidence that further programming of the test equipment may provide an agency with additional information after a field test. In addition to strains, the PDA could collect additional information to assess bridge performance, such as accelerometer data, readings from deflection gauges, and load cell data. This expandability ensures a testing system that can be used to assess various bridge parameters.

Development of a Computerized System to Capture Bridge Inspection Data

This research developed a desktop computer program that could automate data transfer between the PDA and the Pontis database in order to ensure effective, efficient data collection. The

inspector must be provided information about the structure's location, all of the structure's element IDs and definitions, each element's condition state definitions, and any previous inspection data for all bridge elements to be inspected. Additionally, bridge inspectors, who are the end users of Pontis, should find the inspection system to be both user-friendly during data entry and minimally strenuous during the import-export of data from Pontis. An important goal was to provide a system that does not require special training. A report for this project is included in Appendix B.

The system involves two applications: a bridge inspection application and a desktop synchronization application. The bridge inspection application includes electronic data collection forms loaded onto the PDA. Before loading, the application had been designed on a desktop computer using MobileVB, a software tool for developing PDA applications. The PDAs tested in this research included Hewlett Packard iPAQ h1945 and iPAQ h5455, though the bridge inspection applications can function on any PDA running the Microsoft Pocket PC operating system.

The desktop synchronization application, developed in Visual Basic, was designed to smoothly transfer new field inspection data from the PDA to the Pontis database. The bridge inspector connects the PDA to a desktop computer and clicks "Synchronize" on the desktop application form, prompting the program to search the PDA for new inspection data to download to Pontis. Manual data transfer is thus avoided. The application also helps load element and condition state definitions, bridge information, and previous element inspection data, all of which are stored in different files on the PDA, from the Pontis database to the PDA. The application was tested on a Dell computer running the Windows XP Professional and Windows 2000 professional operating systems. For testing, the application was run with a Sybase Adaptive Server Anywhere database, though any ODBC compliant database, such as Oracle or SQL Server, should work too.

A PDA user's manual for this computer program has been written for the Iowa Department of Transportation to assist the bridge element inspection process, and the system was ready to use from the beginning of 2005.

Use of Pontis Bridge Management Software to Develop an IBAMS

This research developed and implemented a working Pontis database for the Iowa DOT. Tasks included customizing the default values for the state of Iowa and verifying the software for the Iowa DOT. A report for this project is included in Appendix C.

Initial customization ensures that the BMS accurately models Iowa's bridge system and generates projects appropriately. The Pontis user's manual was used to calibrate the following five default values in Pontis:

- Agency replacement costs for bridges
- Agency MR&R costs for bridges
- Deterioration rates
- Pontis rules such as look-ahead, scoping, and major rehabilitation

- Policy matrix

After modifying the default values, simulations were run to compare the performance of Pontis to the performance of the Iowa DOT's current maintenance schedule.

It is clear from this research that Pontis will be unable to recommend projects and actions that match the projects currently planned by the Iowa DOT, which are based on engineers' recommendations. However, the results of Pontis are intended as a guide for managing the current bridge network, which relies on economical analysis to distribute the limited funds of an agency. Recommended actions must still be examined carefully to ensure reasonable projects. However, by properly updating the Pontis database, funds can be distributed more efficiently, and the condition of the bridge network can be improved. Software with the complexity of Pontis will require both time and continual data entry to improve the reliability of the management recommendations and ensure that the evolution of the BMS keeps up with the continually changing standards and policies of the agency. Still, continually updating the database may not necessarily converge on the typical maintenance strategy of the Iowa DOT.

**APPENDIX A. UTILIZATION OF HANDHELD FIELD TESTING SYSTEM FOR
IMPROVEMENT OF BRIDGE LOAD RATING VALUES IN PONTIS**

Utilization of Handheld Field Testing System for Improvement of Bridge Load Rating Values in Pontis

October 15, 2004

Word Count: 7,469

Patrick Stein
Iowa State University – CTRE
2901 S. Loop Dr., Suite 3100
Ames, IA 50010
515-296-6686
Fax 515-294-0467
pstein@iastate.edu

ABSTRACT

Due to the growing number of structurally deficient bridges in the United States, methods for determining the structural performance of in-service bridges is vital to the preservation of the nation's bridge network. By utilizing field testing, the response of the bridge due to a known traffic load can be assessed, and more accurate structural performance can be determined.

The objective of this research is to develop a field testing system that can be used assist the Pontis Bridge Management software in selecting suitable bridge candidates for repair or replacement. In conjunction with current development of a handheld device with Pontis inspection forms, development of a data collection system utilizing a handheld device that collects field test data to assist in the structural assessment of bridge structures will be completed. This will include the programming of the device, testing and verification of the system's accuracy and usability, along with the methodology used to assess structural performance. A summary of how this system can improve the structural assessment of an in-service bridge will be included, along with how this system can be utilized to assist the Pontis Bridge Management System software in selecting bridge candidates for repair and replacement.

The completed research outlines the use of a handheld data-acquisition system that can be used to improve the load rating of in-service bridges. Further development strategies are presented and their applicability to integration with the Pontis software.

INTRODUCTION

The Iowa Department of Transportation (IA DOT) currently owns and maintains over 4,000 bridges and culverts on the state highway system. The structural adequacy of these structures has been left to simplified rating equations and continual visual inspection. With heightened concern for the condition of these aging bridges, different solutions have been presented. Methods have been developed to test bridges using applied instrumentation and assess the bridges condition from the collected data. Bridge Management Systems (BMS), however, relies heavily on visual inspection to assess the condition of bridge structures. Field testing of in-service bridges has yet to be linked to the recently accepted Bridge Management System for determining allocation of funds by agencies. Although continual visual inspection of bridges is required for a BMS to succeed, these inspections are providing limited information about the performance and the capacity of bridge structures.

The development of an economical data acquisition system that is portable and can be efficiently used on bridge structures could provide a link between visual inspections and field measured values. By pursuing simplicity in the system interface and installation, tests could be completed by persons with limited engineering background. Not only could this concept prevent bridges from being replaced that are thought to be structurally deficient, but could also aid in estimating bridge condition in the database.

BACKGROUND

Pontis Bridge Management System

Managing the nation's bridges includes tracking the inspection of structures, maintenance needs, along with allocation of funds. Due to the complexity of this, many Bridge Management Systems (BMS) have been developed. A BMS is software designed to aid in the organization of a bridge network, and assist in allocating funds which ensure the most benefit to the users. Pontis, the most widely used BMS, has been selected by the Iowa DOT to manage their current bridge network. The program is dependant on mathematical formulations to determine benefit cost ratios, inflation, deterioration of individual elements, as well as additional functions to ensure the highest bridge network condition for a given budget. This program was developed by the FHWA, and is continually being updated by AASHTO to allow additional customization for an agency's needs.

Utilizing Field Testing

Although many agencies have implemented the Pontis BMS and are currently utilizing its capabilities to determine the maintenance needs of their infrastructure, little structural performance of their bridges is truly known. Although continual visual inspections are being done on an element level, the bridge's response to traffic loads is the primary concern for the safety of the users.

Several of researchers have presented the shortcoming of visual inspection in providing accurate data for a successful BMS [1, 2, 3]. For example, visual inspection does not permit accurate evaluation of bridge serviceability and safety [1]. By incorporating a bridges' existing state and actual response from field testing, parameters such as induced strain can be used to accurately determine the load rating of a bridge system. Current inspection guides offer limited opportunity for the structural adequacy to be estimated, even from a visual aspect [4]. The Manual for Condition Evaluation of Bridges [5], which outlines procedures for visual inspection, agrees that field testing is an effective means of attaining structural performance parameters of a bridge. This load testing is even more essential to those bridges whose response to live load is in question [5].

For the BMS to be optimized, accurate predictions of the remaining life of a bridge must be achieved [3]. Additional research by Chajes et. al. [2] has confirmed that reliable assessments of condition are essential to ensure proper use of limited funds. This project has lead to the prevention of unneeded repairs and proven that some low load rated bridges had considerable more capacity than traditional equations would imply [2]. This finding is also established by Wipf et. al. [6], and notes the savings of funds that can result from accurate structural evaluation of bridge parameters.

The current and emerging tools for condition assessment of in-service bridges will assist in the development of optimal maintenance and management of bridges [1]. With the equipment required to field test a bridge becoming more economically viable, the benefits to an agency to accurately assess its infrastructure may outweigh the cost of the testing equipment.

Utilization of field measurements allows estimation of various structural properties. An assessment of load distribution, support conditions, along with unintended composite action can all be evaluated through non-destructive testing using strain transducers [6]. This global evaluation can be utilized on bridges made of steel and concrete, along with bridges that contain innovative materials. In addition, structural benefits of various maintenance techniques can be assessed by regularly testing in-service bridges. A histogram of strains may be

created for these bridges that will not only prove as a model of changing bridge condition, but will also provide information on the effectiveness of current maintenance techniques [1, 2].

Structural Response of In-Service Bridges

Although the need for accurate structural capacity and condition assessment has proven beneficial to numerous agencies, the method of testing and evaluation is quite diverse. Due to a bridges behavior, interaction between various elements is difficult to assess. Although the load configuration during a field test is known, the contribution of various bridge elements to bridge performance is often qualitative. Due to this uncertainty in the evaluation, two main methods are being used to quantify structural parameters. The first is outlined in research completed by both [6] and [7], and involves utilizing field test data to “calibrate” or improve a finite-element (FE) model of the bridge. This method adjusts various properties of an initial model of the bridge until it most closely represents a structure that, computationally, best fits the tested data. Gauge location, along with sensor quantity, must be sufficient to accurately estimate the response of the superstructure. Parameters that can be adjusted within the model include the modulus of elasticity of various materials, the end conditions of the bridge, along with the stiffness of major elements. Once the finite element model is completed and calibrated, any load configuration can be applied to the model, representing the response of the in-service bridge to different truck loads.

Drawbacks of such a system include cost of the FE software, along with having personnel with FE background to operate the software. A significant amount of instrumentation may be required in more complex bridges for the program to calibrate itself accurately. Further measures must also be taken to ensure that the vehicle location on the structure is correlated with the measured strain value. These concerns often prove impractical to an agency that is unfamiliar with FE, and also have limited field testing experience.

The second method of utilizing field test data is summarized by research completed by Bakht et. al.[8]. This method involves instrumentation of the critical load carrying mechanisms of bridges. Although instrumentation may not be sufficient to constrain the entire structure within a FE model, the members which will be most effected by live load will be assessed. Gauge location is critical to estimate parameters determined to be of most importance to the agency. These parameters can include neutral axis location of a cross-section, lateral distribution of loads, along with maximum live load strain and an estimate of support conditions. By eliminating a computer model of the bridge, significant assumptions may be required to estimate properties of the bridge elements. However, calculations are more practical for an agency to complete without consultation of specialists.

Pontis Load Rating

The Pontis software currently utilizes a transition probability model to estimate deterioration in different bridge elements. Combined with biannual visual inspections, Pontis uses mathematical methods to assess the performance of bridges, and allocates available funds accordingly. A goal of this research is to improve the performance assessment of bridges, therefore preventing rehabilitation and replacement of bridges that have sufficient strength.

The inclusion of field test data into the Pontis software is inherently difficult due to the division of bridge structures into several elements. Separation of these elements insures more complete visual assessment of the bridge. However, structural interaction of these elements is unavoidable during a field test, making individual element assessment unfeasible. Secondly, the level of this element interaction is vital in the performance of the bridge, therefore separation is undesirable for structural performance assessment. Interaction parameters can include composite action between the deck and girders, end restraint at the abutment, along with distribution of the load between girders. By incorporating the assessment of these parameters within Pontis, more accurate assessment of the structural adequacy will be possible.

Pontis currently separates projects into two categories; functional improvements and preservation actions. Preservation actions are associated with maintaining the physical condition of the bridge, therefore depend on inspection results and deterioration probabilities. Functional improvement projects seek to improve the functionality of the bridge due to deficiencies that can include vertical clearance, bridge width, or bridge strength. Field testing provides an improved assessment of the bridge strength, therefore can deter bridge strengthening projects on structurally sufficient bridges. Pontis associates the strength of each bridge structure with the structural rating. This rating is entered in the appraisal tab of the bridge inspection form, and includes the ability rate the bridge using field testing. Figure 1a shows an example bridge rating page, with the load testing pull-down selected for the Inventory Rating. Bridge ratings are separated into two separate categories; Operating rating level and Inventory rating level. Inventory rating level corresponds to the live load which can safely utilize the existing structure indefinite period of time [5]. The Operating rating level corresponds to the maximum permissible live load, which may cause damage to the bridge over time [5]. Field testing for this research will concentrate on load levels corresponding closer to the Inventory rating level. Tests conducted near Operating rating level and are often termed “proof load tests”, and involve much higher load levels which may be inaccessible by agencies.

Numerous research projects have been completed to assess the utilization of NDE in rating of in-service bridges. Research by [9] outlines basic concepts behind field testing to rate in-service bridges. Many methods have been presented to use field test information to develop an improved rating. These methods often include further analysis, sometimes in search of improving a finite element model. This expanded method for bridge rating is outlined in research by [10]. This more rigorous analysis includes assessment of actual field dimensions, impact factor, both longitudinal and lateral load distribution factor, along with additional considerations. Although this level of input allows for possibly greater increases in the load capacity, few agencies are willing to generate such effort on a statewide plan. From this research, however, it was shown that the dominant factor in increasing load capacity was lateral distribution. Through study of the rating equation, this improvement can be directly applied to the bridge rating, as discussed later. This concept of direct improvement to the rating factor is verified through research completed by [11], however includes field measured strains instead of distribution factor.

OBJECTIVES

The objective of this research is to develop a field testing system that can be used assist the Pontis BMS in selecting suitable bridge candidates for repair or replacement. In conjunction with current development of a PDA capable of storing Pontis inspection forms, development of a data collection system utilizing the same handheld device will be completed. This will include research on available hardware and software, and the programming of the device to accurately record test data. Testing and verification of the system's accuracy and usability, along with the methodology used to assess structural performance will also be completed. A summary of how this system can improve the structural assessment of an in-service bridge will be included, along with how this system can be utilized to assist the Pontis Bridge Management System software in selecting bridge candidates for repair and replacement.

SYSTEM CONFIGURATION AND PROGRAMMING

The first step in developing the handheld data acquisition system involved determining the capabilities of handheld devices and their compatibility with available data acquisition hardware. Handhelds have many different names including Personal Digital Assistant (PDA), Palm Pilot, or Pocket PC. PDA is a general term that includes handhelds that operate on either the Palm OS operating system or the Pocket PC operating system. Palm Pilot and Pocket PC refer to the operating system that is used in the device, but can also be used as a general term to describe a handheld computer.

Due to the limited application of PDA's as data collection devices, it was found to be easier to select companies that could provide signal conditioning of the data, and then determine the needed operating system to ensure compatibility. Signal conditioning refers to the manipulation of a signal or voltage, into a more accurate and recordable value. This is accomplished by providing consistent excitation to the gauge, along with gaining of the signal to a more distinct value. Strain gauge signals are typically gained by 100 to 1000 times the original signal to provide the storage device an opportunity to decipher changes in voltage.

Due to the infancy of the concept, few companies could supply hardware capable of recording numerous channels of data simultaneously. National Instruments, however, had experience with such a system and advertised 16 channels of acquisition. The system could also be utilized with either operating system, so the selection of available PDA's increased. It was determined that the HP iPAQ h5150 was proven capable by National Instruments, and had adequate memory and processing to accomplish field testing. The transfer of data between the signal conditioning unit and the PDA was through a PCMCIA card, typically used in Laptop computers. This card could be used in various PDA's with expansion pack capabilities. The iPAQ had expansion pack capability which included an extended battery, which was deemed necessary for field testing. Although National Instruments advertised 16 channels of acquisition, the initial hardware purchase included only 8 channel capability, with the capability to expand to 16 channels. This was done to insure the hardware was capable for our particular bridge testing application.

The gauges used in the field testing are Bridge Diagnostics Incorporated (BDI) full-bridge strain transducers. These gauges are simple to install and reusable, therefore applicable for economical field testing by a state agency. Figure 1b shows a typical transducer being installed in the field. Following grinding the surface clean, the gauge is glued to the member using a quick setting epoxy.

National Instruments utilizes Labview programming software and various drivers to communicate between the PDA and the signal conditioning unit. Due to the limited computing power of the PDA, some functions of Labview cannot be used; therefore programming was simplified to attain efficient storage of the data. This programming, which is completed on a PC, is then "built" for the PDA by drivers included with the Labview PDA

module. Advanced functions such as real time plotting were investigated, yet proved incapable by the limited computing power and development of the Labview PDA software.

SYSTEM TESTS

The data collection system was configured for a full-bridge gauge configuration, and was initially tested utilizing a load cell for the single channel data acquisition program. Following success of the single channel program, transducers were then used to test the data collection system. Although these initial tests provided no basis for accuracy, due to the loading being arbitrary, it did verify the collection of data, the recording rate, along with the sensitivity of the system. Initial tests of the system were completed relying completely on the battery power from the PDA expansion pack. This battery, although capable of providing adequate power for a single channel, was underpowered for multiple channel acquisition. Secondary tests were then completed with a series of 9 volt batteries powering the signal conditioning unit and providing excitation to the transducers. This was deemed adequate for a short-term solution to the battery problem.

The first test to verify the accuracy of the system was conducted in the laboratory using a small section of aluminum beam, simply supported and loaded with steel weights. The PDA system was tested against the venerable Bridge Diagnostic Inc. collection software. Four BDI transducers were applied, two on each flange. Each system was run separately, yet collected strain data at the same rate. The results are shown in Fig. 2a, with the BDI system shown in heavier line weight. Offset of the data in the abscissa axis is due to unequal loading rates of the beam. As shown in the figure, the BDI system has a much higher sensitivity to input signal than the PDA system. The BDI system fluctuates approximately 0.3 microstrain, when the PDA system fluctuated 3 microstrain in the verification tests. Due to this large variation, it was difficult to assess the accuracy of the data acquisition system, however proved reliable enough for expansion to 16 channel capabilities due to the relatively similar magnitudes and strain profiles. This test also did not verify the applicability of the nine volt batteries, due to the limited duration of the test, and only exciting four gauges. It was determined that these issues would be verified during various field tests of in-service bridges.

Following this lab test, the system was expanded to 16 channels, and the signal conditioning unit was modified to include connectors for gauge cables and a power switch. The system is shown in Figure 1b. Each connection on the signal conditioning unit transfers data for 4 gauges. The Labview program was also expanded to accept data from 16 channels, as advertised by National Instruments. However, initial tests recorded only 15 channels correctly. National Instruments was contacted, and it was verified that a bug existed in the software preventing 16 channels of acquisition from being recorded. Therefore the system was now limited to 15 channels of acquisition. The PDA system screen layout is shown in Fig. 2b, detailing the various controls of the system.

FIELD TESTS

An objective of this project is to configure a system that is applicable for various bridge types. Therefore tests were scheduled for both steel girder bridges as well as prestressed concrete girder bridges, and incorporated some innovative materials. These field tests were conducted in conjunction with a test where the BDI hardware was being utilized, therefore provided a direct comparison of test results. Gauge locations were the same, as well as truck paths over the bridge.

IA 92 Steel Girder Bridge

The first bridge that was tested was a 3-span steel girder bridge originally built in 1938, then retrofitted with additional exterior girders in 1967. This bridge is located in Pottawattamie County on Iowa Highway 92, near the town of Griswold. The original bridge was constructed with integral abutments; however the girders were constructed noncomposite. Due to this strength deficiency, additional exterior girders were added, and constructed composite with a custom barrier detail. Further strengthening was completed by adding Fiber Reinforced Polymer (FRP) plates to the bottom flanges of all of the girders in 2003.

The current performance of this bridge configuration is difficult to assess without the assistance of a field test. By field testing, properties of the bridge can be estimated to assist in the evaluation of its current strength. Estimation can then be made on the effectiveness of the strengthening efforts. This bridge is especially unique, due to the exterior girder stiffness being much greater than interior girders due to composite action, along with the spacing of girders being irregular, and the properties of the interior girders being different. A typical section of the bridge is shown in Figure 3a.

Gauges were installed on the top and bottom flange of the steel girders, both at midspan locations and near the abutment. Readings were first taken by the BDI system with the truck at crawl speed. Identical runs were then completed using the PDA system to collect strain data. Fifteen channels of acquisition were completed, with 9

channels reading midspan strains, and 6 reading abutment strains. The BDI strain profiles were then compared to the PDA data acquisition strain profiles to assess the accuracy of data collection. Figure 3b shows a direct comparison of selected gauges with significant strain magnitudes. Like colors represent equivalent gauge numbers, therefore should have not only similar magnitudes, but also strain profile shapes. The BDI system is shown in heavier line weight. Although the profiles were of the same basic shape, the PDA system consistently recorded strain magnitudes lower on certain gauges, and somewhat higher on others. Some small differences in magnitude were expected, due to slight changes in truck position on the deck for each run. However two runs were completed for the BDI software and the magnitudes were nearly identical between similar truck paths. The BDI software is run on a laptop computer, and has a powered signal conditioning unit that receives electricity from a generator on the sight. The PDA system is self powered, and is relies on an excitation of 5 volts when the BDI system uses 10 volts. Increase in excitation voltage provides cleaner readings, due to a higher signal to noise ratio. However, excessive noise was not recorded on either systems strain profiles, so this was initially disregarded as the problem.

It was determined that the data collection system operated correctly, and stored readings at the specified rate, and the programmed sensitivity. However, an additional field test was to be conducted to retest the systems accuracy prior to deeming the system complete.

53rd Street Bridge, Prestressed Concrete Girder Bridge

The second test was conducted on a three span prestressed concrete girder bridge, with various deck configurations on each span. This bridge is located on 53rd Street in Bettendorf, Iowa, in Scott County. The PDA system was utilized on the east span, which had a Fiber Reinforced Polymer (FRP) deck with a thin wearing surface. Subsequent spans had conventional reinforced concrete decks, with the west span having epoxy coated bars and the middle span having uncoated bars. The girders were integral with the abutment for both end spans, and the bridge width was constant across the bridge. The BDI system was used on both end spans, to assess the effectiveness of the FRP decking when compared to a conventional reinforced concrete deck of similar span length. The PDA system was only used on the FRP deck span; however similar truck paths were run for both systems.

This was the first FRP deck in the United States to utilize composite bending action with pre-stressed concrete girders. The connection detail of this design is shown in Fig. 4a. Structural properties the bridge were determined using conventional specified equations, however true behavior of this design type was somewhat uncertain. Gauges were installed in the center of the bottom flange of the girders, and the side of the top flange. Identical truck paths were completed using both the BDI software and the PDA system to collect strain data. Fifteen channels of acquisition were completed, all reading at midspan of the girders. The BDI strain profiles were again compared to the PDA data acquisition strain profiles to assess the accuracy of data collection. Figure 4b shows a direct comparison of a selection of gauges which had significant strain magnitudes. Like colors represent equivalent gauge numbers, therefore should have not only similar magnitudes, but also strain profile shapes. The BDI system is shown in heavier line weight. This test proved that all gauges reading greater than 20 microstrain had significant loss in magnitude compared to the BDI values. However, strain profile shapes remained consistent with the BDI system, so it was determined that the system was underpowered. Although the nine volt batteries provided sufficient voltage to excite the gauges, the current provided by the small batteries was not capable of returning the signal without losses. This was not apparent in lab tests, due to the connection being significantly shorter between gauge and signal conditioning unit. Field tests were conducted with gauges being up to 75 feet away from the signal conditioning unit, compared to 20 feet during laboratory testing. Also, full 15 channel acquisition was never tested in the lab; therefore additional strain on the batteries was expected during field testing. Research of battery options was completed, and a rechargeable 12 volt battery was purchased, capable of extended acquisition with 2.2 Amp hours of power. Figure 1b details the completed system components, including the rechargeable battery.

East 12th Street Bridge, Steel Girder Bridge

The East 12th Street Bridge is a 2-span high performance steel girder bridge with integral abutments and a conventional cast-in-place deck. This bridge was constructed in early 2004, and spans over Interstate 235 in Des Moines, IA. This test was conducted to insure the performance and reliability of the new battery. At any transverse section of the bridge, the girders have identical section properties and spacing. The PDA system was used to test strains near the north abutment of the bridge. During this test, the BDI software as well as wireless monitoring was utilized in conjunction with the PDA system.

Three separate load paths were conducted at crawl speed, and were each run twice to insure consistency in the readings. The data collected was then directly compared to the BDI software for accuracy. PDA system test magnitudes and strain profiles matched the BDI software, within the range of the PDA's collection sensitivity. Although numerous digits of reading were being stored, it was still felt that the sensitivity of the system was a

concern for calculation accuracy. As shown in Fig. 2a, determination of strain magnitude can become difficult with the lower sensitivity PDA data acquisition system. National Instruments was contacted, and upon further programming the sensitivity was effectively doubled for the system. This translates to a sensitivity of 1.5 microstrain, versus the previously tested 3 microstrain.

METHODOLOGY

Bridge rating is based on the simplified expression shown below in Equation (1). The Iowa DOT rates its bridges using this equation, and then enters each rating into the Pontis database. Therefore it is desirable to improve the accuracy of these rating factors with a simple approach, utilizing the additional information the field test data has provided to improve the already rated bridge network. Parameters such as end restraint and neutral axis of the girders can be qualitatively assessed, but offer no direct relationship to the rating equation. However, distribution of the live load to individual members is directly assessed in section 6.7.3 of AASHTO's Manual for Condition Evaluation of Bridges [5]. The option exists to attain this distribution factor from field tests, therefore improving the rating of the tested bridge. Current ratings within the IA DOT database were found using empirical equations within bridge design specifications. As shown in Equation (1), the rating equation is inversely proportional to the live load effect. This allows the distribution factor to be directly changed in the equation without further calculation. If the distribution factor originally used in the rating calculation is known, multiplying the current bridge rating by the ratio shown in Equation (5) satisfies the improvement of the load rating. The distribution factor used in the original rating is needed, as well as a field test distribution factor estimate. This ratio can then directly improve the rating value, preventing unneeded replacement and rehabilitation. Care must be taken, however, to insure that the bridge is capable of additional load. A highly deteriorated bridge may distribute loads effectively, yet have insufficient strength properties to justify an increase in the bridge load rating. Additional research is in progress to assess this issue.

An additional assumption made through field testing of bridges is that the bridge responds in a linear manner up until the point of specified rated load allowance. However, nonlinearities can be present as the load nears the bridges ultimate load capacity. Release of locked supports, cracking of concrete in tension, along with other mechanisms can occur during larger displacements due to extreme live load conditions. These parameters affect the Operating rating level, and are often not triggered by Inventory load levels. Therefore careful consideration must be made when using the below methodology to improve the Operating rating of in-service bridges.

$$RF = \frac{C - A_1 D}{A_2 L(1 + I)} = \frac{1}{L} \left(\frac{C - A_1 D}{A_2(1 + I)} \right) \quad (1)$$

$$L = (D.F.)_{CODE} L_{TOT} \quad (2)$$

$$RT = (RF)W \quad (3)$$

Combining Equations

$$RT = \frac{W}{(D.F.)_{CODE} L_{TOT}} \left(\frac{C - A_1 D}{A_2(1 + I)} \right) \quad (4)$$

Rating Equation Improvement Using Field Test Distribution Factor

$$RT = \frac{W}{(D.F.)_{CODE} L_{TOT}} \left(\frac{C - A_1 D}{A_2(1 + I)} \right) \left\{ \frac{(D.F.)_{CODE}}{(D.F.)_{FIELD}} \right\} \quad (5)$$

RF = rating factor for the live-load carrying capacity

C = capacity of the member

D = dead load effect on the member

L = live load effect on the member

I = impact factor to be used with the live load effect

A₁ = factor for dead loads

A₂ = factor for live loads

(D.F.)_{CODE} = Distribution Factor determined from empirical equations

(D.F.)_{FIELD} = Distribution Factor determined from field test data

L_{TOT} = Total live load effect on the bridge structure

RT = bridge member rating in tons

W = weight of nominal truck in tons used in determining the live load effect

The distribution factor (D.F.) is the fraction of live load transferred to the most heavily loaded girder under maximum live load effects. Therefore, during field tests attempts are made to position the truck to produce maximum effects on the girders. This is typically done by lining a set of wheel-lines directly over a girder centerline for one path, along with straddling a girder with the truck on another path. Estimation must also be made to estimate multiple presence of trucks; therefore a path can be aligned to represent a second truck on the bridge at the same time as one of the first paths. These three paths are the best estimate of maximum live load effects on the bridge. Strain readings from these paths must then be combined to estimate the distribution of loads. During the field test, the strains are assumed to be directly related to the bending moment in the section. Therefore the D.F. is the fraction of moment carried by the most heavily loaded girder, as shown in Equation (6). Determining the D.F. can be done by expanding basic beam theory equations for the girders, which was originally developed by [12]. As shown in Equation (7), inertias and neutral axis locations of each girder must be estimated for the tested bridge. Symmetry of the bridge can be used to estimate girder properties that are not instrumented. On wider bridges strain magnitudes were shown to decrease significantly as the transverse distance from the load path increases. Girder strains for these distanced girders can therefore be ignored, and optionally instrumented due to their insignificant effect on the load distribution.

$$D.F. = \frac{M_G}{\sum M_G} \quad (6)$$

$$\varepsilon = \frac{Mc}{EI} \quad M_G = \frac{\varepsilon_G E_G I_G}{c_G}$$

Combining Equations

$$D.F. \cdot_j = \frac{\frac{\varepsilon_{G_j} I_{G_j}}{c_{G_j}}}{\sum_{i=1}^n \frac{\varepsilon_{G_i} I_{G_i}}{c_{G_i}}} \quad (7)$$

Methods are currently being developed to determine the inertias and neutral axis locations of girders directly from test strains. Currently, neutral axis location is being estimated from segments of the strain profiles that are recording significant strain magnitudes. Figure 5a shows the neutral axis plot for the IA 92 Bridge. Clearly interpretation of neutral axis location is necessary, due to variations as the truck changes position. Therefore a statistical program ensuring accurate estimation of the neutral axis is desired. Once this location can be confidently estimated, the composite girder properties of the in-service bridge can be estimated. Figure 5b shows an example D.F. calculation for the IA 92 steel girder bridge. Neutral axis locations were estimated from strain profiles, and inertias of the composite girders were then determined using the steel girder design properties. Properties of the exterior girders were determined using the assumption of fully composite with the deck and barrier. This was verified by comparing test strain magnitudes and estimated neutral axis location with that of conventional design methods. It was found that the correlation was adequate to utilize the codified values for inertia and neutral axis. However, test strains in the farthest girder were neglected due to insignificant magnitude, and as an illustration for distanced girders that may not be instrumented. Due to this bridge being initially designed Noncomposite, Operating rating load levels may influence the effective bond between the deck and girders. Due to this nonlinear mechanism largely effecting beam stiffness, it would be ill-advised to apply any increase to the Operating rating strictly from this test.

Further research is being completed to assess bridges that may demonstrate improved distribution, yet have insufficient overall strength to justify an increase in capacity. A methodology that eliminates the need to further analyze and instrument the bridge is preferred. This will insure the systems compatibility with personnel with limited engineering experience.

CONCLUSIONS

The completed research provides a basis for the improvement of bridge load rating using field test data. This improved load rating can be directly entered into the Pontis database, which can then assist in the assessment of repair and rehabilitation projects. Further development could allow for field test data to be stored in the Pontis database, and be utilized not only in the improvement of bridge load rating, but also serve as a record of bridge performance.

The components and software provide agencies with an economical method to better assess performance of their bridge network. Through collection of these field measurements, this evaluation will allow an agency to prevent premature replacement or rehabilitation of structures, allowing funds to be utilized on truly deficient structures. Utilizing this handheld data acquisition system is not limited to bridge testing to improve load rating, however this was determined to be the most effective method to improve the Pontis BMS selection of bridges with deficient strength. With proper engineering judgment, various bridge types can be instrumented and tested with any loading, and assessments of bridge performance can be estimated.

The PDA was primarily used as a storage device, with little data manipulation capability due to the limited driver functions. However, recent development of additional drivers for handheld programming insures that further programming of the test equipment could provide additional information to an agency following a field test. In addition to strains, the PDA could collect additional information beneficial to bridge performance. With the proper components added, the data acquisition system could collect accelerometer data, readings from deflection gauges, as well as load cell data. This expandability insures a testing system that can be used for the assessment of various bridge parameters.

RECOMMENDATIONS

Recommendations for utilizing field test data to improve Pontis Bridge Load Ratings are as follows:

- **Field testing of in-service bridges should include only the test truck at crawl speed.** Distribution factor cannot be accurately determined with the above methodology when dynamic effects or additional ambient traffic is included. The truck should have adequate load to produce significant strain magnitudes ($\pm 20 \mu\epsilon$) to assess D.F. and neutral axis location. Trucks used in discussed field tests weighed a minimum of 55 kips, and produced adequate strain magnitudes. The system is fully capable of recording dynamic strain readings, as well as strains due to ambient traffic. However these effects prohibit accurate D.F. assessment.
- **Instrument bridge girders near midspan.** The most critical region for effective distribution of loads is at or near midspan. Gauges should therefore be placed at the same transverse location of the bridge near midspan. Gauges should be instrumented on the bottom and topmost section of the girder to insure significant strain magnitudes and accurate neutral axis estimation.
- **Load Rating Improvement methodology is only valid for girder bridge types.** The data acquisition system is capable of collecting strains on any bridge type or element surface; however distribution methodology is only valid for girder bridges. The system could still be utilized to assess live load strain in bridge members to insure safety of older structure types. Periodic bridge testing could also provide a histogram of strains, modeling the changing bridge condition, and will provide information on the effectiveness of changing maintenance techniques.
- **Careful analysis should be conducted prior to improvement of Operating rating level.** Although distribution of loads may not be affected by certain structural nonlinearities, assessment should still be made on possible nonlinear mechanisms. If any of these mechanisms involve changes to the individual beam properties, direct improvement of the rating value is invalid.
- **Bridges with significant skew should be more thoroughly instrumented to assess distribution.** No bridges that were field tested under this research included a skew on the bridge. Instrumentation location is vital on skewed bridges to assess load path issues related to distribution. Further research on field testing methods to assess skewed bridge distribution factors would further benefit agencies assessment of in-service bridge performance.
- **Further research on field test data integration with BMS databases should be conducted.** This research provides only one method of assisting the Pontis database with project evaluation through improvement of the bridge load rating. Further developments should be completed to assess the lack of structural evaluation in the preservation projects which Pontis recommends. With AASHTO's continual

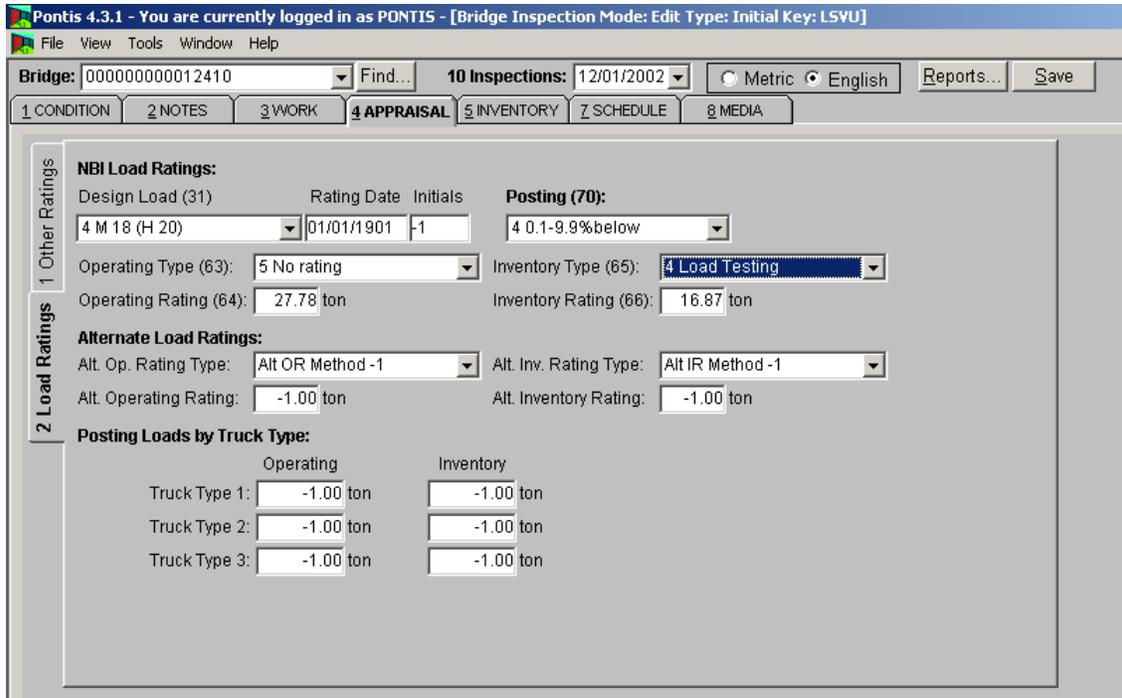
development of Pontis, an open door to entering field test measurements would allow continual development of the integration of non-destructive evaluation of bridges with an agency's BMS.

REFERENCES

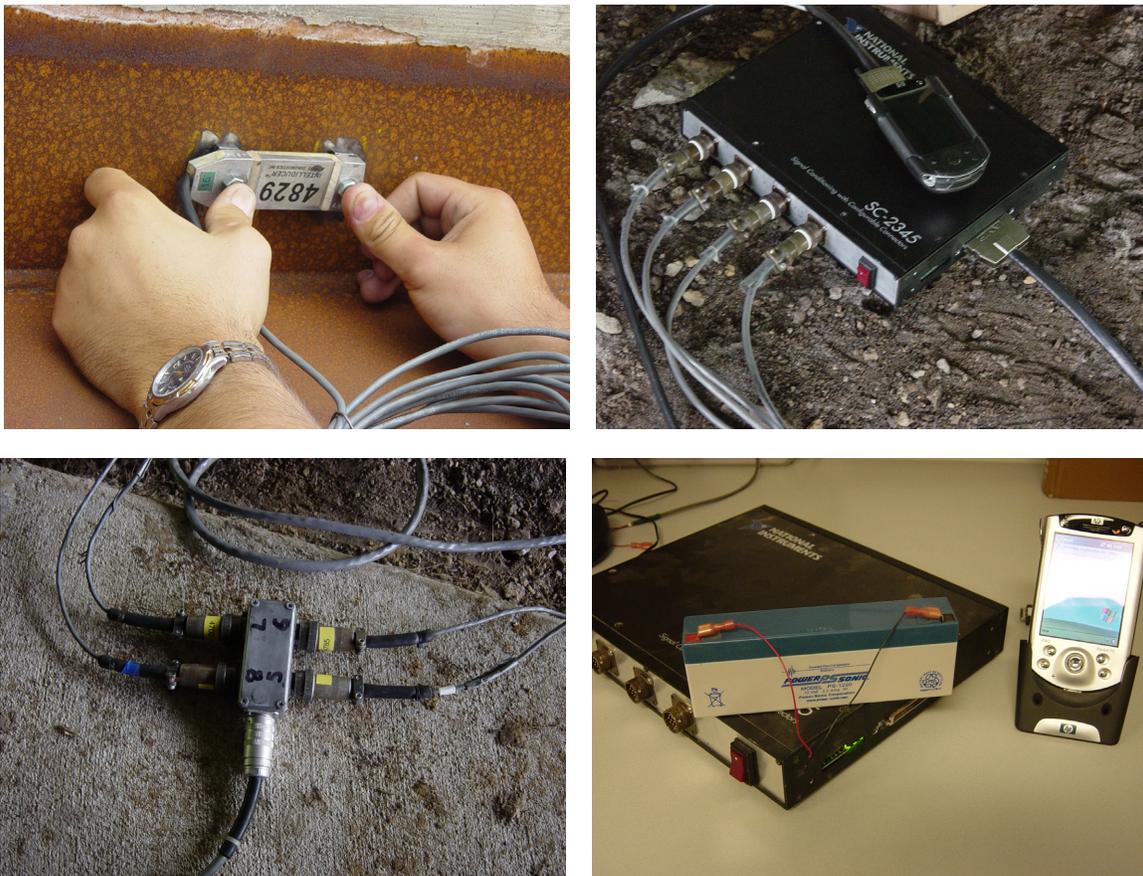
1. Aktan, A. E., Farhey, D. N., Brown, D. L., Dalal, V., Helmicki, A. J., Hunt, V. J., Shelley, S. J. (1996). "Condition Assessment for Bridge Management" *Journal of Infrastructure Systems*, Vol. 2, No. 3, September, 1996, 108-117.
2. Chajes, M. J., Shenton III, H. W., O'Shea, D., Chaudhri, M. (2003). "Bridge Testing to Enhance Bridge Management in Delaware" *Transportation Research Circular, 9th International Bridge Management Conference*, April, 2003, 201-203.
3. Organization for Economic Co-operation and Development (OECD). (1992). *Road Transport Research, Bridge Management*. Paris, France.
4. Federal Highway Administration (FHWA). (1988). *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges*. Washington, D.C.
5. American Association of State Highway and Transportation Officials (AASHTO). (1994). *Manual for Condition evaluation of Bridges, Second Edition*. Washington, D.C.
6. Wipf, T. J., Klaiber, F. W., Phares, B. M., Wood, D. L. (2002). "Evaluation of a Bridge Load Testing/Rating System"
7. Farhey, D. N., Naghavi, R., Levi, A., Thakur, A. M., Pickett, M. A., Nims, D. K., Aktan, A. E. (2000). "Deterioration Assessment and Rehabilitation Design of Existing Steel Bridge" *Journal of Bridge Engineering*, Vol. 5, No. 1, February, 2000, 39-48.
8. Bakht, B., Jaeger, L. G. (1992). "Ultimate Load Test of Slab-on-Girder Bridge" *Journal of Structural Engineering*, Vol. 118, No. 6, June, 1992, 1608-1624.
9. Cai, C., Shahawy, M. (2003). "Understanding Capacity Rating of Bridges from Load Tests" *Practice Periodical on Structural Design and Construction*, Vol. 8, No. 4, November 1, 2003
10. Barker, M. (2001). "Quantifying Field-Test Behavior For Rating Steel Girder Bridges" *Journal of Bridge Engineering*, Vol. 6, No. 4, July/August, 2001.
11. Cai, C., Shahawy, M. (2004). "Predicted and Measured Performance of Prestressed Concrete Bridges" *Journal of Bridge Engineering*, Vol. 9, No. 1, January 1, 2004.
12. Stallings, J. M., and Yoo, C. H. (1993). "Tests and rating of short-span steel bridges." *Journal of Structural Engineering*, 119(7), 2150-2168.
13. American Association of State Highway and Transportation Officials (AASHTO). (1996). *Standard Specification for Highway Bridges*. Washington, D.C.
14. Cambridge Systematics, Inc. *Pontis Release 4 User's Manual*. AASHTO, Washington, D.C., 2001
15. Cambridge Systematics, Inc. *Pontis Release 4 Technical Manual*. AASHTO, Washington, D.C., 2001

List of Figures

- Figure 1 Pontis load rating screen and system layout pictures.
- Figure 2 Data acquisition system verification results and PDA screen layout.
- Figure 3 IA 92 Steel Girder Bridge details.
- Figure 4 53rd Street Prestressed Concrete Girder Bridge details.
- Figure 5 Example distribution factor analysis for IA 92 Bridge.

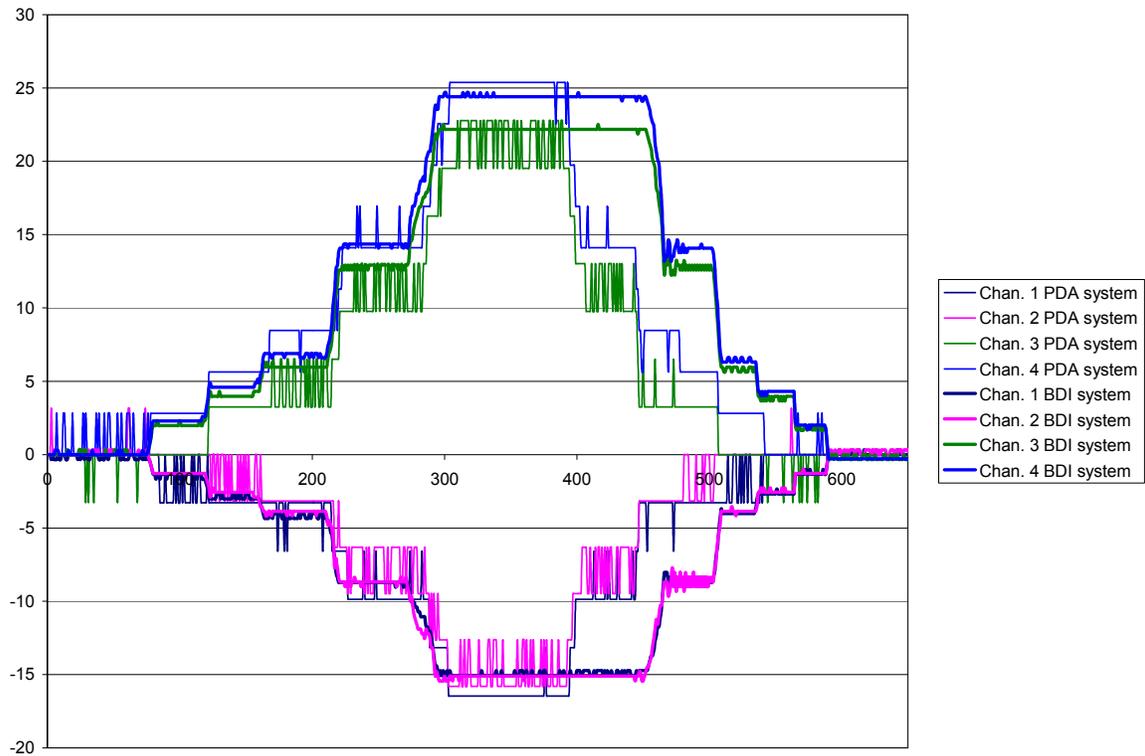


a. Pontis load rating screen layout.

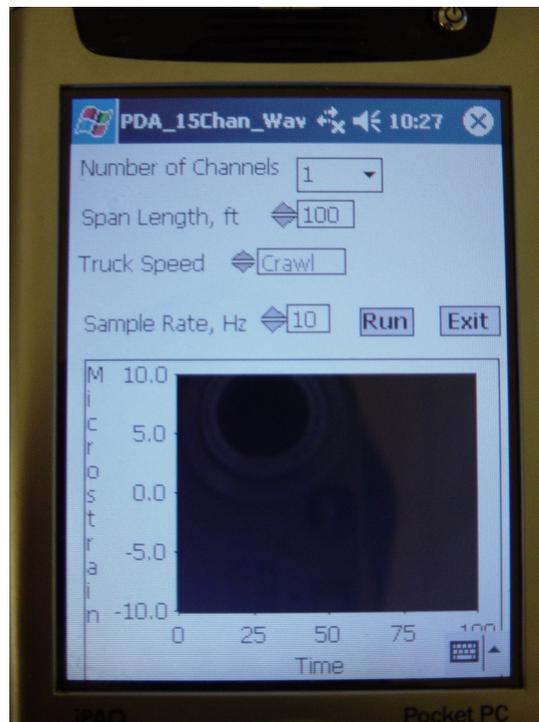


b. Handheld data acquisition system details.

FIGURE 1 Pontis load rating screen and system layout pictures.

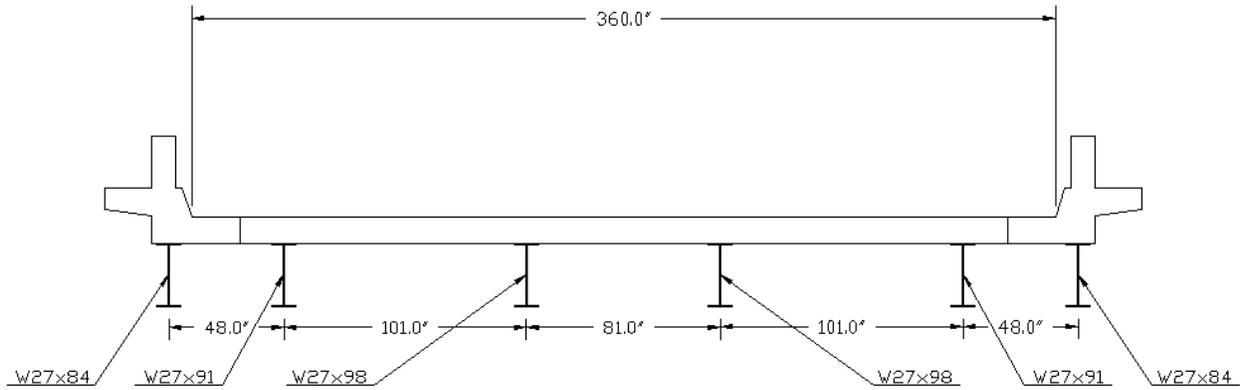


a. PDA system verification results.

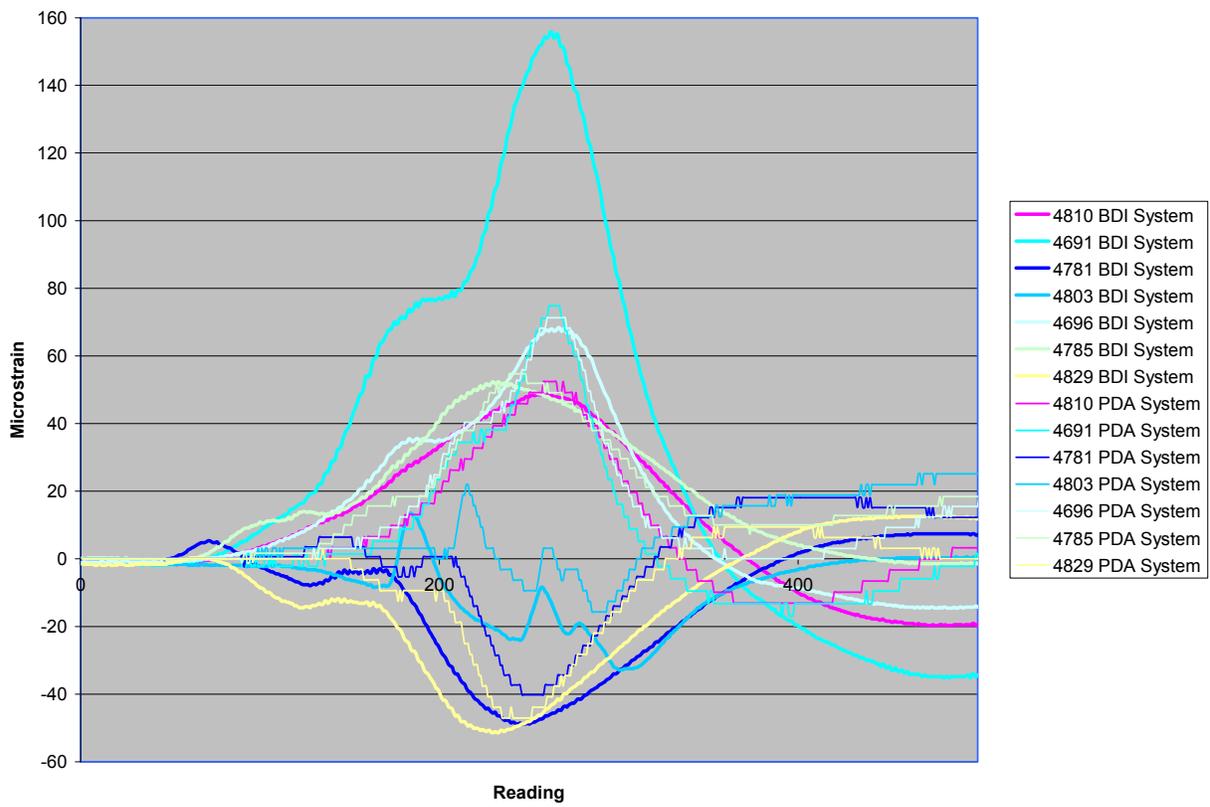


b. PDA data acquisition screen layout.

FIGURE 2 Data acquisition system verification results and PDA screen layout.

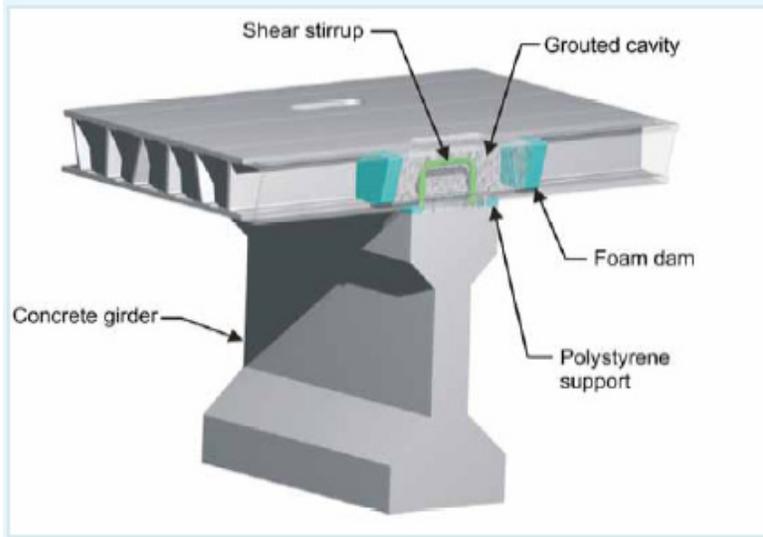


a. IA 92 typical bridge section.

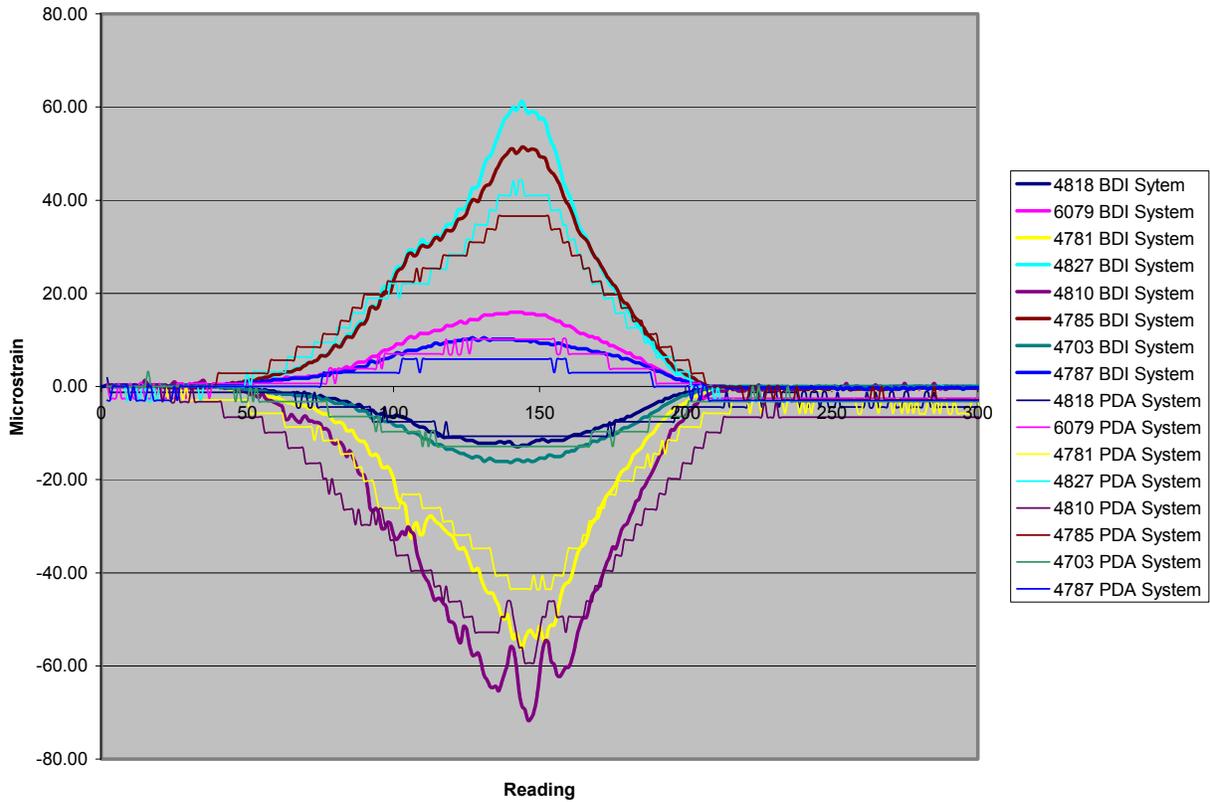


b. IA 92 bridge strain profile comparison.

FIGURE 3 IA 92 Steel Girder Bridge details.

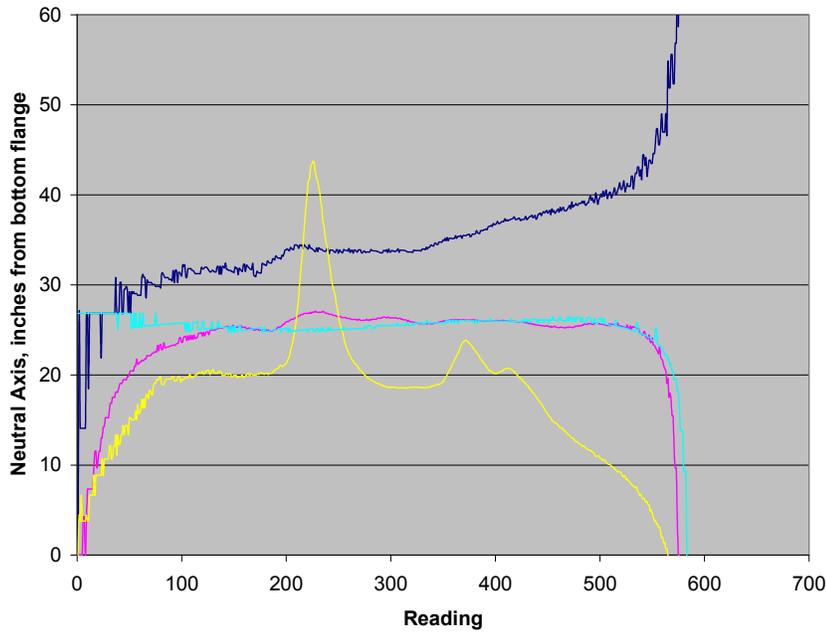


a. 53rd Street Bridge typical FRP deck to girder connection detail.

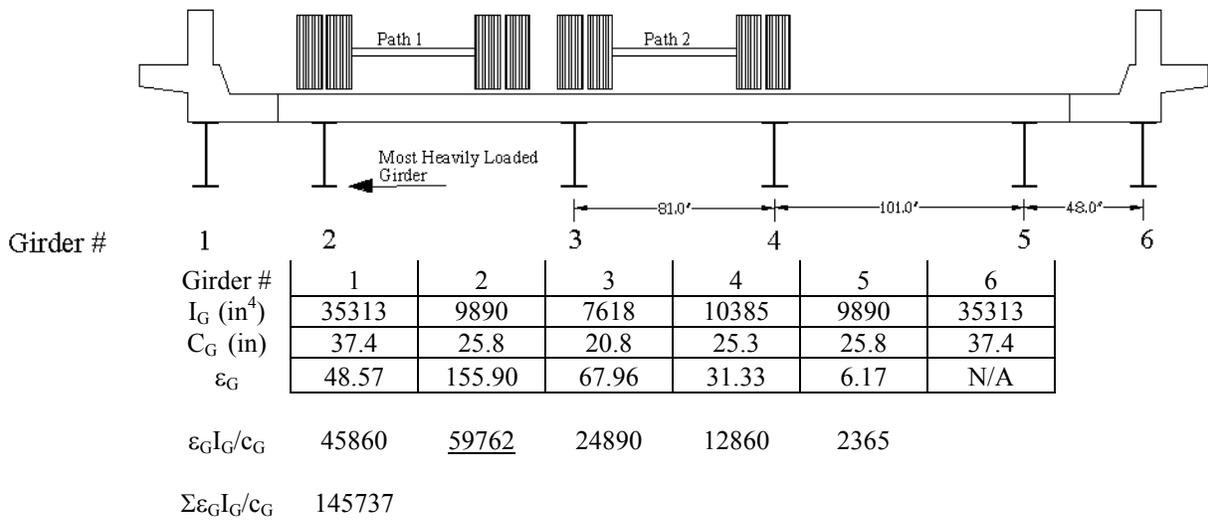


b. 53rd Street Bridge strain profile comparison.

FIGURE 4 53rd Street Prestressed Concrete Girder Bridge details.



a. Example neutral axis plot for IA 92 Bridge girders.



$$D.F._j = \frac{\frac{\epsilon_{G_j} I_{G_j}}{c_{G_j}}}{\sum_{i=1}^n \frac{\epsilon_{G_i} I_{G_i}}{c_{G_i}}} = \frac{59762}{145737} = 0.410 \quad (D.F.)_{FIELD} = 0.410 \quad (\text{Per Truck})$$

$$(D.F.)_{CODE} = \frac{s}{5.5} = \frac{(101 + 48)/2}{5.5(12)} = 1.13 \quad (\text{Per Wheel Line}) \quad (D.F.)_{CODE} = 0.564 \quad (\text{Per Truck})$$

$$\left\{ \frac{(D.F.)_{CODE}}{(D.F.)_{FIELD}} \right\} = \frac{0.564}{0.410} = 1.38 \quad (38\% \text{ Increase})$$

b. IA 92 Bridge distribution factor calculation example.

FIGURE 5. Example distribution factor analysis for IA 92 Bridge.

**APPENDIX B. PDA BASED BRIDGE INSPECTION FOR PONTIS BRIDGE
MANAGEMENT SYSTEM**

PDA based Bridge Inspection for Pontis Bridge Management System

by

Krishna Chaitanya Kallam

A creative component submitted
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Civil Engineering

Program of Study Committee:
Edward Kannel, Major Professor
Omar Smadi
Tom Maze
Carl Roberts

Iowa State University

Ames, Iowa

2004

TABLE OF CONTENTS

INTRODUCTION	4
BACKGROUND	4
Current Data Collection Practices And Issues.....	5
Iowa DOT Inspection Efforts.....	5
LITERATURE REVIEW	6
Iowa Department of Transportation.....	6
Maryland State Highway Administration.....	6
South Carolina Department of Transportation.....	7
Wisconsin Department of Transportation.....	7
USER REQUIREMENT.....	7
1. Data to be collected.....	7
2. Inspection Information required	8
3. Transfer of data to and from Pontis	8
SYSTEM ARCHITECTURE	8
Bridge Inspection Application.....	9
Desktop Synchronization Application.....	9
THE INSPECTION PROCESS	9
1. Identifying the Bridge.....	9
2. Entering New Element Inspection	10
3. Transferring data to Pontis database.....	10
CONCLUSION.....	11
REFERENCES	12
FIGURES.....	13
APPENDIX A - PROCEDURE:.....	18

INTRODUCTION

The traditional approach used by transportation agencies allocating maximum funds to bridges in critical condition against routine maintenance almost always results in gradual deterioration of overall condition of bridges (1). This created the need for implementing a bridge management system that will provide a logical approach in allocating funds to bridges in order to improve their condition over a network level rather than just bridge level. The bridge management system thus emphasizes the need of preventive maintenance on bridges, i.e., maintaining bridges before they reach an unsafe state, over deferred maintenance (1).

Pontis is a bridge management system (BMS) used by many transportation agencies for managing inspections, budgets, and project development for bridge assets (1). It is currently licensed by American Association of State Highway and Transportation Officials (AASHTO) to around 45 state Departments of Transportation (DOT) and other agencies nationally and internationally (2). However, for bridge management decisions based on the analysis of the database system to correctly reflect the actual bridge condition, accurate bridge inspection data are essential. Quality control without compromising the speed in the collection of data is the most important aspect to be considered for any data collection system.

The research aims at developing, implementing and evaluating a bridge inspection-data collection system using a Personal digital assistant (PDA). A data collection system was developed for HP iPAQ Pocket PC which provides a bridge inspector with various capabilities such as identifying a bridge based on certain attributes, retrieve and display previous element level inspection information for the bridge and allow user to enter new inspection data and save it on the PDA. In order to minimize the bridge inspector's manual effort in importing the field data collected on PDA into Pontis, a user interface is designed on the desktop with synchronization capabilities for keeping data in the Pontis database and the PDA both accurate and up-to-date.

BACKGROUND

During the past few years, the limited resources for bridge maintenance management, combined with increasing number of bridges becoming deficient every year has paved way for adopting a comprehensive BMS that will help agencies allocate limited bridge funds in a more cost effective manner. The Intermodal Surface Transportation Sufficiency Act of 1991 recognized the need of preventive maintenance on bridge infrastructure. Under this legislation, the states were required to implement a fully operational Bridge Management System (BMS) by October of 1998 in order to be eligible for federal funds (1). Pontis BMS that was first developed by Cambridge Systematics in 1989 and later expanded to meet the increasingly complex asset management demands of transportation agencies through partnership with AASHTO, the Federal Highway Administration (FHWA), and state departments of transportation (DOT) (2). With increase in use of bridge management systems, and after establishment of new FHWA regulations requiring bridge inspection to be performed on an element-level basis, inspection data management requirements have increased tremendously (7).

During the evolution of Pontis bridge management, it was decided by the Pontis Technical Advisory and the Pontis developer that although the current National Bridge Inventory (NBI) ratings from 0 to 9 of the bridge deck, superstructure and substructure were easy to communicate, a more sophisticated approach of dividing a bridge into elements and rating these

elements individually using a set of three to five condition states would yield better results in terms of depicting the accurate condition of the bridge. Using this approach, the total quantity of an element can be divided into one or more states depending on how the element is defined. For example, ***

Current Data Collection Practices and Issues

Current bridge inspection practices require a substantial amount of field and office work. A complete inspection report always consists of several pages containing element inspection data that are presented in tabulated format following the bridge inspection manual and the coding sheets. They also include notes, or summary of findings, for each element and sketch drawings. Preparing an inspection report requires significant time, and retrieving this information is always difficult to accomplish in a reasonable time. In case of Iowa DOT, there are about 4000 bridges on its state highway network and an average of about 8 elements per bridge. It is recommended that every bridge be inspected and element inspection data recorded for at least once in every two years for the Pontis BMS decisions to make good sense. It can thus be calculated that about 32000 elements must be inspected in 24 months.

In addition to collecting huge amount of data, there is an issue of maintaining the quality of the data being collected. The inspector(s) or the inspection team needs to carry with them a document containing all the element definitions with their corresponding Pontis element identification numbers. Although an inspector might recognize the element by looking at it, it is very tiresome to write down the element name or looking in the element definitions document to write the corresponding Pontis identification number. Since each element has three to five condition states, the inspector needs to look at the definitions to figure if an element has three, four or five condition states and divide the element's condition accordingly. Also, there are 'margin math' errors at the time of inspection, where the inspector must keep tab of the fact that, if using a percentage system, sum of the percentages assigned to individual states of an element should be equal to 100, or, if using a quantity approach, sum of quantities in individual states should be equal to the total quantity of the element. Once the inspection is done for the bridge, the next steps involve entering this information into the Pontis software. All of these steps provide opportunities for significant human errors in addition to taking considerable amount of time.

Iowa DOT Inspection Efforts

The current inspection practices of the Iowa DOT consist of coding sheets where information relating the element condition data is entered for every bridge ID. It was observed that, at the time of entering data into an electronic format, approximately 10% of the sheets contained one or more types of human errors described in the previous paragraphs. These sheets are sent back to the corresponding inspection teams for corrections. Since the time elapsed between data collection and data entry into electronic format is considerably long, an average of 6 to 12 months, the corrections that are returned are only the best recollections of the inspectors since the bridges are not inspected again. This is a great concern and hence developing an automated element inspection system that checks errors and guides an inspector through the whole inspection process is greatly justified. The first part of the current research addresses this issue. The objective here is to reduce the effort required by the bridge personnel to record and process bridge inspection data, and reduce the errors to a minimum.

Since Pontis is used as the bridge management decision support tool, the inspection data collected using PDA has to be transferred to the Pontis database. With the current Iowa DOT inspection practice, data in the coding sheets are manually entered into a 'Microsoft Access' database before transferring the data into Pontis. There are only two checks applied to validate data at the time of data entry, whether the bridge ID entered by user is a valid bridge ID and whether the element condition percentages total to 100 (margin math error). Some errors like the wrong element numbers on the coding sheets are not validated at this time. Adding to this, there are errors in the data entry itself. For the Iowa DOT, these errors amounted to almost 5% of the total data, including the wrong element numbers present in the coding sheets. The second part of the research addresses this issue. The objective is to develop a program that can be run on the desktop computer after connecting to the PDA, and automate the transfer of data from the PDA to the Pontis database.

This current research is part of a bigger research project undertaken by Center for Transportation Research and Education (CTRE) for Iowa Department of Transportation (DOT) to develop, implement, and operate an integrated bridge asset management system (IBAMS) for the state of Iowa.

LITERATURE REVIEW

It is very important to automate the bridge inspection process to conform to a data acquisition system that does not differ substantially from the current paper-based system in order to gain acceptance for the field personnel (7). There are several automated data collection systems available at present. These systems, which include bar code scanners, voice recognition systems, pen-based computers and personal digital assistants (PDAs), attempt to create more user-friendly forms of data input than the traditional input using the keyboard (7). This section provides the literature review relating to various automated data collection systems that have been developed.

Iowa Department of Transportation

A research team at Iowa State University developed an automated data collection (ADC) program, which can be run on a laptop or a desktop, for the Iowa DOT in 1996 (6). This program provides the bridge inspector information on the bridge, element and condition state definitions for all elements, and enables the inspector to enter and save element inspection data. However, when entering an inspection, the elements have to be selected from a list of all the elements defined in the Iowa DOT database. Using this program, one can also narrow the element search using the criteria for bridge type, super structure, deck, etc. There is no provision for looking at the previous inspection data for that bridge. Also, this program is limited to running on a 100% IBM compatible computer (desktop or laptop). Currently, the Iowa DOT bridge inspectors are not using this system as the element inspection data for the past 9 years are present on paper format only.

Maryland State Highway Administration

Around 1995, Trilon Inc., a company that specializes in delivering mobile computing and multimedia solutions for the transportation industry, developed a PDA based data collection system for Pontis for the Maryland State Highway Administration (MSHA) in association with

Federal Highway Administration (FHWA). To use this system, the inspection team has to first 'check-out' the bridges that need new inspections into a specially formatted file, called the Pontis Data Interchange (PDI) file, and load it into the PDA. Once the new field inspections are completed, the inspection team can then 'check-in' the data into Pontis using the reverse process.

South Carolina Department of Transportation

In 1995, a pen-based bridge inspection system was developed for the South Carolina DOT (SCDOT). A pen-based computer is a lightweight notebook computer that utilizes a pointing pen for data entry. The data acquisition system is called the Automated Bridge Inspection System (ABIS) and was developed using the Padbase Software Development Kit (7). This system also works by checking out bridges into a PDI file, and downloading it into the pen-based computer. A translation program is then used to convert this file to a "dBase" format that can be read by the ABIS application. After completion of the new inspection, data are converted back to the Pontis compatible text file that can then be imported into Pontis. The ABIS program has features like provisions to draw sketches for scour lines and access to previous element inspection data. Also, it is a complete bridge data collection system including provisions for entering NBI data, element data, bridge scour, structural flag, etc. An economic analysis indicated that the number of man-hours saved using this system paid for the price of 14 pen-based computers. This greatly justifies that automated hand-held data collection systems would be very useful and cost beneficial.

Wisconsin Department of Transportation

The Wisconsin Department of Transportation (WisDOT) conducted a multi-year study beginning 1994 to determine the feasibility of deploying a new mobile-based system for collecting pay quantity information on WisDOT construction projects. They developed three different applications for full-sized tablet PC's, the Casio Zoomer and Apple's MessagePad. The testers reported that these systems are simple, easy to use and definitely an asset to their fieldwork. Cost analyses indicated timesavings sufficient to pay for the devices and development within one construction season.

It can be summarized from the above literature that automated data collection systems are definitely very beneficial for bridge inspectors in terms of time saved, accuracy of the data and increasing the efficiency of the whole bridge inspection process.

USER REQUIREMENT

This sections details the user requirements for a automated PDA based inspection system. These requirements are developed in line with the current inspection process. The data requirements include data required to identify a bridge and aid in the data collection, and the data that is actually collected in the field. The other requirements include transfer of data to and from the desktop computer running Pontis software to the PDA.

1. Data to be collected

In Pontis, a structure (bridge, culvert, tunnel, etc.,) is divided into individual component types known as elements. Each of these elements has pre-defined set of condition states ranging from three to five. For example, a 'Deck' element is defined to have five condition states and an 'Unpainted Steel Open Girder' is defined to have four. A condition state of an element is defined by the extent of damage or deterioration of that element. For example, for 'Deck' element, the condition states are defined as follows:

- If element shows little or no deterioration, then condition state 1
- If combined distress area of element < 2% of deck area, then condition 2
- If distress area between 2 and 10%, then condition state 3
- If distress area between 10 to 25%, then condition state 4
- If distress area > 25%, then condition state 5

A bridge inspector conducting a Pontis based element inspection must assign the total quantity of element into one or more of these condition states and record the data accordingly. For example, the inspector must be able to record that, for bridge ID '3410' and element 12, which is the 'Deck' element, x% of the element lies in condition state 1, y% in condition state 2 and so on. The total percentage must be 100. An inspector must be able to record data in percentages or quantities. Additional data to be collected include total element quantities, if changed from the previous inspection, any new elements added to the bridge, and notes for each element. The tool that will be developed should allow the bridge inspectors to accomplish this easily.

2. Inspection Information required

In view of eliminating as much paper work as possible, it is required that complete information necessary to the bridge inspector for conducting a bridge inspection in the field is saved in the PDA itself. Hence, information pertaining to the location of the structure, all element IDs and definitions for that structure, and the condition state definitions for each element must be provided to the inspector. Also, previous element inspection data for all elements of the bridge to be inspected must be available to the inspector. If no previous inspection is available for a bridge, an inspector must be able to add elements to that bridge using the element definitions and create a new inspection for it.

3. Transfer of data to and from Pontis

In order to minimize the manual effort needed to load previous inspection data to the PDA and the new element inspection data back to Pontis, a tool is needed to keep the data between the PDA and the Pontis are synchronized.

SYSTEM ARCHITECTURE

The bridge inspectors, who are the end-users, should find the PDA based inspection system as user-friendly as possible at the time of data entry, and the manual effort as minimal as possible at the time of importing/exporting the data to and from Pontis. The goal is to provide a system that does not need any re-training or special training to use the system (4).

Bridge Inspection Application

The bridge inspection application is completely designed on the desktop and then loaded onto the PDA. MobileVB, a Visual Basic® based software that allows you to develop mobile applications, was used to develop the application. The software has an in-built tool to deploy the application on to the PDA. A Booster®, provided by the same company that provides the software, helps in the smooth functionality of the application developed on the PDA. This booster is bundled with application creating a single installation file that can then be loaded onto the handheld device and installed in a single run.

Though the application is tested with the HP models iPAQ h1945 and iPAQ h5455 only, any PDA running the Microsoft's Pocket PC operating system should be compatible with the application built. The application cannot be used on PDAs running on other operating systems such as Palm or Symbian without modifications. Although the program running on the PDA can be used in other operating systems with minor changes to code, the synchronization program on the desktop is specifically designed to handle a Pocket PC PDA and cannot be used otherwise.

Desktop Synchronization Application

For enabling smooth transfer of the field inspection data from the PDA to Pontis database, an application is developed in Visual Basic that runs on the desktop computer and helps in inserting new inspections into the Pontis database. Once the bridge inspector connects the PDA to a desktop or laptop and clicks 'Synchronize' button on the desktop application form, the program automatically searches for new inspections on the PDA and uploads whatever it finds to Pontis. Hence, manual work is completely avoided. Since the element definitions, the condition state definitions, the bridge information and the previous element inspection information are stored in different files on the PDA, the application helps in loading these files from the Pontis database to the PDA. This is helpful whenever an inspector accidentally deletes any of these files or the files get corrupted for some reason.

This application has been tested on a Dell personal computer running windows XP professional and windows 2000 professional operating systems. Though this application was tested with a Sybase Adaptive Server Anywhere database, it should run on any ODBC compliant database like Oracle or SQL Server.

The technical details describing the procedure used for creating the PDA and the synchronization applications are given in Appendix A.

THE INSPECTION PROCESS

The following steps describe the bridge inspection process in detail emphasizing the features of the application and the user interface.

1. Identifying the Bridge

The application starts by displaying a bridge list and some attributes of the bridge currently selected in the list, as shown in figure 1. Starting a new inspection is as simple as picking a bridge ID from the list and clicking the ***Enter New Inspection*** button. An inspector can also search for a bridge based on some easily remembered bridge attributes.

The ***Find Bridge*** form shown in figure 2 a) helps the inspector to enter complete or partial known information on attributes like the district the bridge is located in, the county the bridge is located in, facility carried by the bridge, feature intersected by the bridge and the bridge ID.

2. Entering New Element Inspection

The next step for an inspector after identifying a bridge is to view previous element inspection data and enter new inspection for the bridge. This is done in the ***Element Inspection*** form, shown in figure 3. To avoid any kind of errors in choosing the elements for a bridge, only those elements corresponding to the selected bridge ID and for which a previous element inspection has been done are displayed in the list. This form also contains the element and state definitions for each element, which are displayed when ***Long Name*** and ***State*** buttons are clicked respectively. It is possible to access these data at any point of the data entry. Some important features provided in this form include:

- If no previous element inspection data is present for a bridge, the inspector will be prompted to add new elements for that bridge. New elements can also be added for bridges that have previous element inspection records using the ***Add Element*** button. The same feature can also be used to change total quantity for an existing bridge element. The ***Add/Edit Element*** form is shown in figure 4.
- An inspector can enter new inspection data in actual quantities as well as in percentages.
- At every point of data entry, the application checks whether the individual percentages or quantities sum up to the total percentage, which is 100), or the total quantity of the element respectively, and warns the inspector accordingly. The inspector must decrease the percent or quantity in one condition state before increasing the percent or quantity for another condition state.
- A new inspection record is saved as soon as the inspector clicks the element list. A ‘*’ is added to the end of element name in the dropdown list indicating that an inspection for this element has been updated. At any time, the inspector can select any element in the list and update the inspection data. Once inspection is updated for all elements, the inspector can click ***Finish*** to view a confirmation page with new inspection data, and confirm to add the inspection to the database.

3. Transferring data to Pontis database

The final step is to upload the new inspection data from the PDA to Pontis. All the inspector needs to do is connect the PDA to the desktop computer, run the desktop application and then click ***Synchronize*** button on it. The desktop application checks the PDA for new element inspection data and updates the Pontis database. The database settings have to be correct in order for this procedure to work correctly. More information can be found in the

User's Manual prepared with this application. The inspector can use desktop application to load files containing element and state definitions, bridge and element inspection information on to the PDA. The number of bridge and element inspection records loaded onto the PDA can be restricted by selecting a district from the drop down list of the *Create and Deploy PDBs* form shown in figure 8.

CONCLUSION

A PDA based inspection system has been developed and a user's manual has been written for the Iowa Department of Transportation to aid in the element inspection process of bridges. The system is ready to use from the beginning of 2005 for inspection of Iowa DOT bridge elements. There is no doubt that this system will definitely benefit the inspectors in terms of the time savings and accuracy of the data, and improve efficiency of the whole inspection process. The system will finally benefit the decision makers using the Pontis Bridge Management System to make much confident bridge maintenance and management decisions as the decisions are based on better inspection data than before.

REFERENCES

1. Edward, C. *Bridge Management Systems Literature Review and Search*. ITI technical report no. 11, November 1996, Infrastructure Technology Institute, 1801 Maple Avenue, Evanston, IL 60201-3140. http://www.iti.northwestern.edu/publications/technical_reports/tr11.html
2. Cambridge Systematics, Inc. *Pontis Release 4 User's Manual*. AASHTO, Washington, D.C., 2001
3. O'Conner, D. and Drumm, R. *Bridge Management Systems-Advancing the Science*. Transportation Research News 173, July-August, 1994, Transportation Research Board 500 Fifth Street, NW Washington, DC 20001- USA
4. Trilon Inc., *Pda-Based Field Data Collection For Pontis*. Proceedings from 12th Annual International Bridge Conference and Exhibition, June 1995. Available at WWW: http://www.trilon.com/trilon/papers/IBC_95_PDA_Paper/paper.htm
5. Fanous, F., Greimann, L., and Soni, A. *Automated Methods for Collecting Bridge Inspection Data in the Pontis Format*. Semisesquicentennial Transportation Conference Proceedings, May 1996, Iowa State University, Ames, Iowa
6. Elzarka, H., Bell, L., Floyd, R. *Automated Data Acquisition For Bridge Inspection*. *Journal of Bridge Engineering*, Vol. 4, No. 4, November 1999. ASCE 1801 Alexander Bell Drive, Reston, Virginia USA
7. Bosscher, P., Yeazel, D. *Using Handheld Data Collectors in Highway Construction for Accounting and Materials Management*. Final report to the Wisconsin Department of Transportation, Dept. of Civil & Environmental Engineering, University of Wisconsin-Madison, Madison, WI

FIGURES

Bridge Information

Menu Help

Bridge ID: 000000000003410

Maintenance Number: 8297.20080

County: Scott

District: Cedar Rapids

Feature Intersected: OVER I-80

Facility Carried: JERSEY RIDGE RD

Inspection Done:

C:\Documents and Settings\kkallam\My Documents\PD\Awork\BridgePDA_ver4\BridgePDA_v

Figure 1: Initial form that displays information regarding the bridge ID.

Find Bridge

Bridge ID (Contains):

District: County: scott

Feature Intersected:

Facility Carried:

Show Only UnInspected Bridges

Brkey	County	District
0	Scott	Ce
5	Scott	Ce
1	Scott	Ce

Element Inspection

menu Help

Element Condition Data

Bridge ID: 000000000003410

Element Number - Short Name: 12 Unp Conc Deck

Insp Date: 8/1/2002

Quantity: 5400.0 IN (SF)

State	Old	New	Total
1:	100.0	100.0	100%
2:	0.0	0.0	
3:	0.0	0.0	
4:	0.0	0.0	
5:	0.0	0.0	1

Figure 2 (a) and (b):
based on some

Display for finding a bridge
information provided by the user.

Figure 3: Form displaying element inspection data for bridge selected on the “Bridge Information” form.

Confirm Inspection

Bridge ID: 000000000003410

Element 12 Unp Conc Deck
Total Quantity = 5400.0 (SF)
Inspection date = 3/10/2004
State 1: 100.0
State 2: 0.0
State 3: 0.0
State 4: 0.0
State 5: 0.0

Go back and Edit Data Confirm and add to Database

Figure 4: Form showing for confirmation of new inspection data entered in the field for an element before addition to database

Add/Edit Element Data
 Menu Help
 Bridge ID: 000000000003410
 Element ID and Name:
 ▼ Select
 Element Description: Long Name
 [Empty Text Box]
 Quantity: [Empty] IN
 Note: Quantity shown initially is the current quantity of this element.
 Cancel Add Element

(a)

Add/Edit Element Data
 Menu Help
 Bridge ID: 000000000003410
 Element ID and Name:
 ▼ 12 - Unp Conc Deck
 Element Description: Long Name
 This element defines those concrete bridge decks with no surface protection of any type and construc
 Quantity: 5400 IN (SF)
 Note: Quantity shown initially is the current quantity of this element.
 Cancel Add Element

(b)

Figure 5: Display for adding elements or updating quantities of an element for the selected bridge

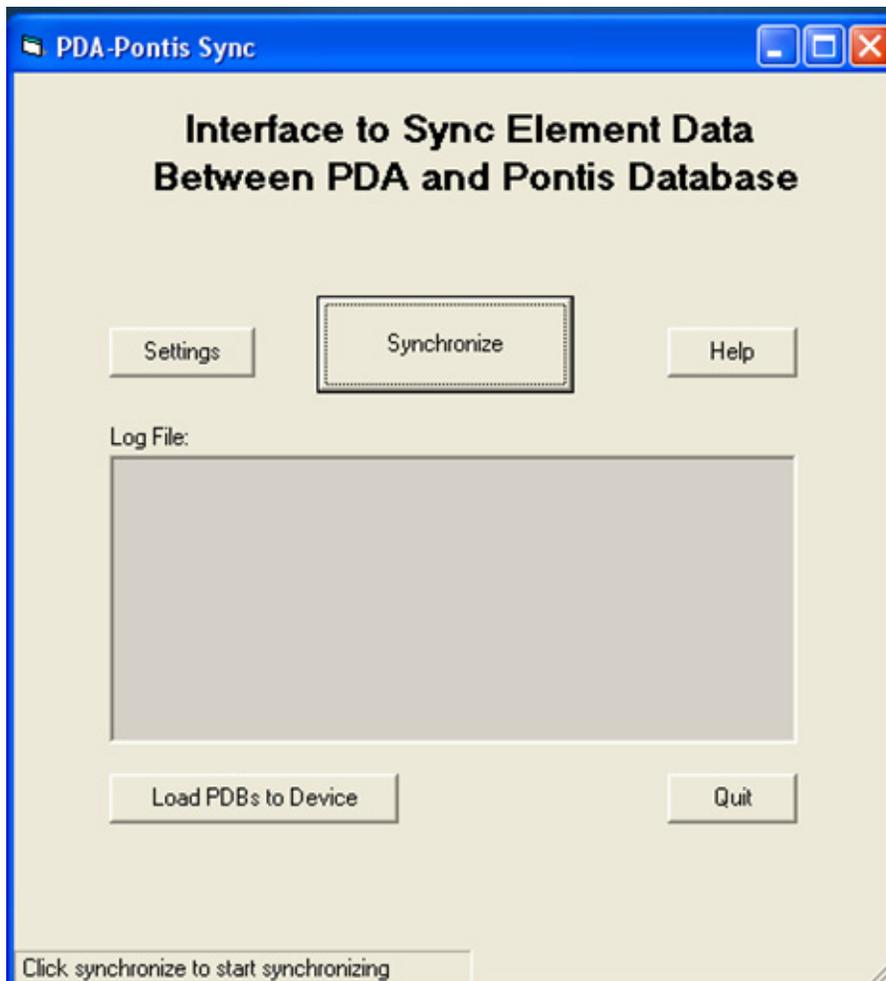


Figure 6: Form for synchronizing new inspection data entered into the PDA with the Pontis Sybase database

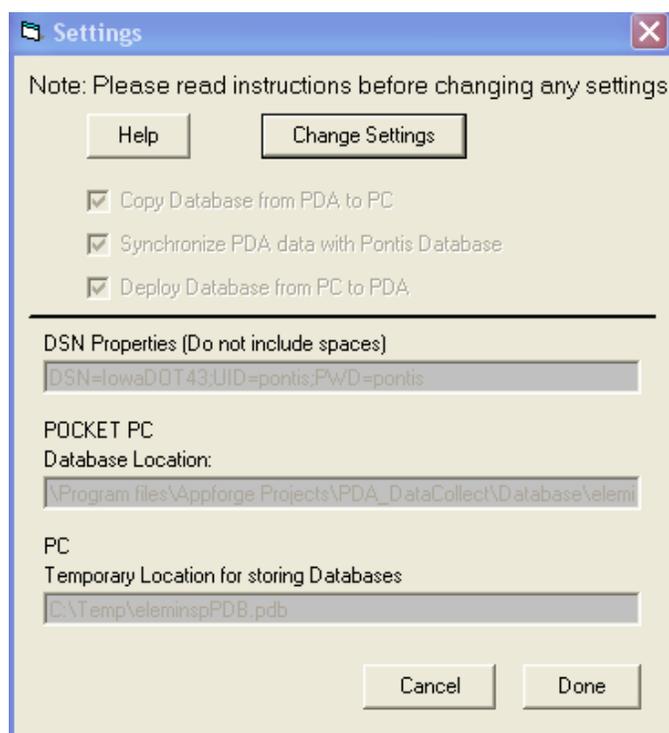
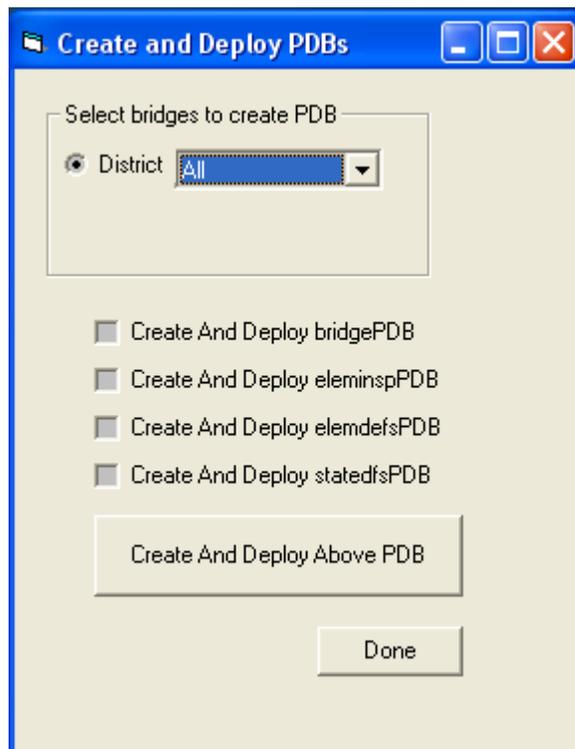


Figure 7: Form displaying synchronization settings



The image shows a software window titled "Create and Deploy PDBs" with a blue title bar and standard Windows window controls (minimize, maximize, close). The main content area is light beige and contains the following elements:

- A section titled "Select bridges to create PDB" with a radio button selected next to the label "District". To the right of the radio button is a dropdown menu currently displaying "All".
- Four unchecked checkboxes, each followed by a label:
 - Create And Deploy bridgePDB
 - Create And Deploy eleminspPDB
 - Create And Deploy elemdefsPDB
 - Create And Deploy statedfsPDB
- A button labeled "Create And Deploy Above PDB" centered below the checkboxes.
- A "Done" button located at the bottom right of the window.

Figure 8: Form for deploying various databases to the PDA.

APPENDIX A - PROCEDURE:

- For storing data, a native palm database (PDB) format is used. Although this is not a native Pocket PC format for storing data, the PDB database is accessible by applications using mobileVB in any handheld operating system. This database format was chosen because it exists in the same format on the desktop as well as any handheld operating system. So the underlining code of the application remains same irrespective of the target operating system (the only condition being that the target handheld must be mobileVB compatible). A PDB can have only one table and hence four separate PDBs were created, first one containing bridge information data (shorter form of the ‘bridge’ table in Pontis Sybase database), second one containing element definitions (shorter form of “elemdefs” table), third one containing state definitions for each element (from “statedfs” table) and final and most important one containing the previous element inspection data for all bridges (taken from “eleminsp” table)
- It was thought that the initial information that a bridge inspector will need is regarding selecting and/or confirming a bridge ID with the help of some features of the bridge which he can notice in the field, like the facility carried by the bridge, district and county in which the bridge is located and feature intersected by the bridge. This helps in avoiding any prior memorization of bridge IDs that need to be inspected on a given day. For this purpose, the initial form or display after starting the application shows a list of bridge IDs and corresponding information regarding that bridge ID. For this to work, the inspector should keep searching one by one the bridge IDs and match the information related to that bridge. Since this is time consuming, an additional feature is added to the application which helps in finding a bridge based on some “full or partial” but known information provided by the user. Figure 2 a) and 2 b) show the ‘Bridge information’ and the ‘Find Bridge’ forms respectively.

The bridge information is stored in a PDB file named BridgePDB. This file was generated using VB code, basically by executing the following SQL query and storing the resulting data into a recordset and then adding data from the recordset to a PDB file created using mobileVB. Since mobileVB is embedded into existing visual basic, a single program can use methods from both mobileVB and VB.

SQL Query:

```
SELECT brkey, featint, district, county, facility, maintenance_num  
FROM bridge;
```

- The next step for an inspector after identifying a bridge is to view previous inspection data or enter new inspection data for a bridge. This is done in “Element Inspection” form (shown in figure 3). To avoid any kind of errors in choosing the elements for a bridge, only those elements corresponding to the selected bridge ID (for which a previous element inspection has been done) are displayed in the list. Pontis stores these data in a table called “eleminsp”. The following query was used to retrieve element inspection data and create a corresponding PDB file. The element inspection database on the PDA is named EleminspPDB.

SELECT e.brkey AS brkey, e.inspkey AS inspkey, e.elemkey AS elemkey, e.envkey AS envkey, e.elinspdate AS elinspdate, e.quantity AS quantity1, e.pctstate1 AS pctstate1, e.pctstate2 AS pctstate2, e.pctstate3 AS pctstate3, e.pctstate4 AS pctstate4, e.pctstate5 AS pctstate5, e.notes AS notes

FROM eleminsp e, bridge b where e.brkey = b.brkey AND inspkey =

(SELECT max (inspkey) FROM eleminsp j

WHERE j.brkey = e.brkey and elinspdate =

(SELECT max (elinspdate) FROM eleminsp k WHERE k.brkey = e.brkey));

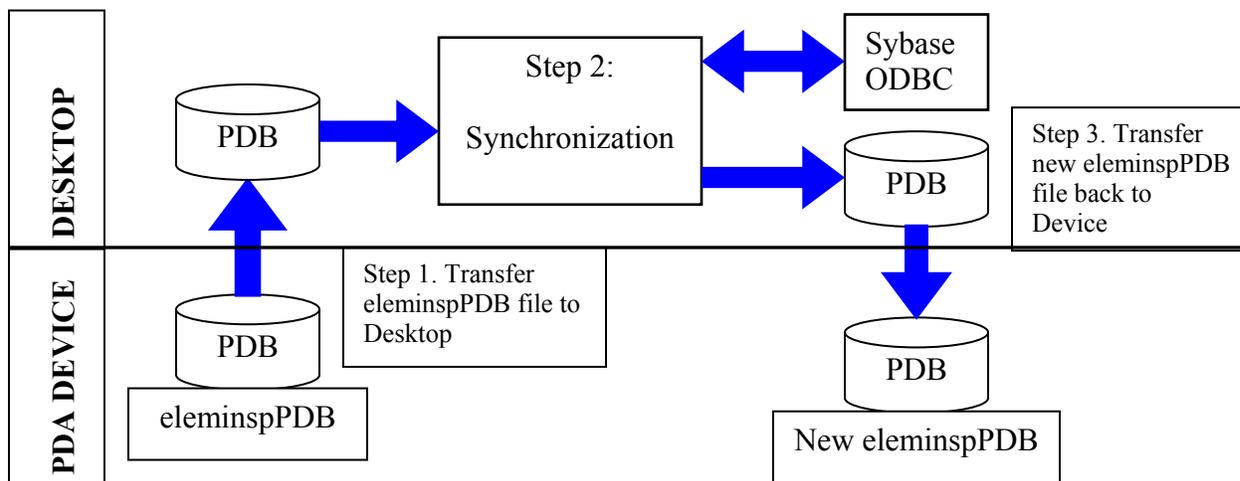
This database contains only the latest inspection data for any element. For example, a bridge may have inspections for years 1998, 2000 and 2002, but only the last inspection, which is 2002, is imported into the PDB. Giving the previous inspection data is considered helpful to the inspector, as he will have a better idea of expected deterioration of bridge elements that he is inspecting. Since carrying any kind of paper is to be avoided as much as possible, this form contains all the information regarding the element name with its definition, and state definitions for each element. It is possible to access these data at any point of the data entry. Some important features provided in this form include:

- If there is no previous element inspection done for any bridge, an opportunity to add new elements to the bridge is given. Also, the same holds for existing elements though it is highly improbable that some bridge elements are removed or added. The main aim at allowing data editing for already present bridge elements is to change the quantities of an element already existing for this bridge.
- An opportunity to enter both in element quantities as well as in percentages is provided.
- Error checks at every point of data entry are done. At every point of data entry, the application checks whether the summation of individual percentages or quantities exceed the total percentage (which is 100) or the total quantity of the element. The inspector can only decrease the percent or quantity in one condition state before increasing the percent or quantity for another condition state.
- The inspector is given a final confirmation checklist after he is finished with entering new inspection for an element where he can confirm and add the data to PDB database. Since, the addition of new element data to the bridge will overwrite the previous element data for that bridge, the confirmation checklist will be helpful if an inspector wants to make changes.
- A ‘*’ at the end of element (in the element dropdown list for a given bridge) indicates that an inspection for this element has already been done. This is given in order to avoid an inspector to keep track mentally of what elements he has inspected and not enter new inspection for an element that has already been inspected.
- If an inspector forgets to enter element inspection data for one or more elements for a bridge, a warning stating that these elements have been left out is displayed and the inspector is allowed to choose whether to finish those element inspections now or come back and finish later.
- Once the inspector is done with all the elements of a bridge, a ‘*’ is placed at the end of that bridge ID in the ‘Bridge Information’ form so that an inspector can

keep track of which bridges have been inspected previously without going into the 'Element Inspection' form and checking the date of inspections.

The various forms and dialogs related to element inspection are shown in figure 4 and 5. Each time an element inspection is finished and confirmed, the application marks the corresponding "inspkey" (for Pontis bridge inspection key) as "XXXX" which indicates a new inspection is entered for that element. This is done in order for the desktop application to identify the new inspections and add them to the Pontis database. Once the new inspection has been updated, the inspector cannot view the old inspection data for this element since the new data one replaces the old. Hence, he will only be able to see new data which he can still modify if he wishes to.

- The next and the final step is to upload the new inspection data from the PDA to Pontis. For accomplishing this with minimum manual effort, an desktop application has been designed using VB. Some mobileVB methods are also used in this application to accommodate accessing the PDB database and performing some operations on the database. It is necessary to install the ActiveSync software provided by the Pocket PC vendor for any of the operations discussed in this step to run. This step of application can only be used with a PDA operating on a Pocket PC operating system. The reason behind this is the software and methods used to connect to the PDA depend on the type of operating system and the type of PDA being used and hence different from each other. The visual basic code written currently uses methods specifically designed for accessing a Pocket PC from the desktop and hence gives an error if trying to connect to a PDA running any other operating system. The flowchart for accomplishing this step is given below:



* Synchronization Logic: Copy Element inspections marked with inspkey as "XXXX" to the Sybase database. Once the data is updated to Sybase correctly, update correct inspkeys obtained from Sybase database for that year to the PDB database. (inspkey is short for inspection key)

As shown in the flow chart, the synchronization process involves three steps:

1. Copy or transfer the eleminspPDB file, which has the element inspection data.
2. Apply synchronization logic, which basically scans the database for new inspections and inserts these inspections into Pontis' Sybase database by executing an SQL query.

3. The PDB file is copied back to the PDA after marking the new inspections as old so that the application does not try to insert the same data again and again each time the synchronization procedure is run.

Since this procedure is not written for any operating system other than the Pocket PC, it is recommended that only Pocket PCs be used for field inspection. Figure 7 shows the display of this application.

Finally, it is believed that inspection teams are assigned to specific bridges which they normally inspect and that they do not normally go for inspection of bridges outside that area of bridges, and hence there should be a provision to create element inspection PDBs specific to their location or criteria. This will help in reducing the space needed to store eleminspPDB database (which is the largest file in all) on the PDA and hence improving the time taken to access and display data on it, thus improving the overall efficiency of the system. An application is developed and embedded into the synchronization application, which allows the inspector to create and deploy the 'Bridge information' PDB (i.e., the 'bridgePDB' database) and the 'element inspection' PDB (i.e., the 'eleminspPDB' database) for any of the six districts in Iowa. Provision to download the 'element definitions' (the 'elemdefsPDB') and 'condition state definitions' (the 'statedfsPDB') is also included. This will be useful when an inspector accidentally deletes any of the files required for the PDA application to work. Also, this application is helpful when some changes are made to the Pontis database and the inspector wants to keep the PDA database updated.

**APPENDIX C. IMPLEMENTATION AND CUSTOMIZATION OF PONTIS FOR THE
IOWA DEPARTMENT OF TRANSPORTATION**

Implementation and Customization of Pontis for the Iowa Department of Transportation

August 1, 2004

Word Count: 7,476

Patrick Stein
Iowa State University – CTRE
2901 S. Loop Dr., Suite 3100
Ames, IA 50010
515-296-6686
Fax 515-294-0467
pstein@iastate.edu

Omar Smadi
Iowa State University – CTRE
2901 S. Loop Dr., Suite 3100
Ames, IA 50010
515-294-7110
Fax 515-294-0467
smadi@iastate.edu

Fouad Fanous
Iowa State University
Town Engineering Building
Ames, IA 50010
515-294-9416
fanous@iastate.edu

ABSTRACT

The IA DOT has selected Pontis, the most widely used Bridge Management System in the nation, to assist in selecting economical projects for their current bridge network. The widespread application throughout the nation allows for data sharing between states and enhances the calibration process of the program; however individual agency customization is often desired to insure accuracy and reliability in the recommendations.

The objective of this research is to develop and implement a working Pontis database for the IA DOT. This will include a description of selected methodology, and implementation of initial Pontis setup, including initial replacement and MR&R costs, initial development of element deterioration rates, along with all Pontis Rules and a Policy Matrix. Following the finalization of initial Pontis values, different verification methods will be completed to insure reliability in the use of the Pontis software by the IA DOT.

A literature review was completed to determine the available implementation methods, and their relevance to the IA DOT. Additional research and communication was completed to develop new methods for initial estimation of pertinent parameters within the Pontis software. Additionally, input from the IA DOT was utilized when possible to instill confidence in the implementation procedure, and the subsequent recommendations from the Pontis software.

The completed research provides a basis for initial implementation of a Pontis database for an agency with limited historical data. It provides comparisons with planned projects from the IA DOT, and the correlation with Pontis generated recommendations.

INTRODUCTION

As the nation's bridge network continues to grow in complexity to accommodate the increasing demand of travel, the budget of state agencies continues to be limited to maintain the current bridge network. This limitation has led to the development of Bridge Management Systems (BMS). The purpose of a BMS is to optimize the use of limited funds, therefore offering the most economical use of resources, and providing the most benefit to the user. Factors that are accounted for in this process include the annual average daily traffic (AADT) of the facility, the condition of individual bridge elements, cost to repair or replace any bridge elements, and additional factors that insure the most cost effective use of limited funds. For the BMS to function properly, intensive data collection and entry must be completed on a regular basis. A majority of the success of the BMS relies on regular and accurate inspection of the bridge system, along with updates to costs and the policy of the agency using the BMS.

The Iowa Department of Transportation (IA DOT) currently owns and maintains over 4,000 bridges and culverts on the state highway system. As the available funds for maintenance work changes over time, it is vital to have a database that contains the condition of each bridge in the network. Updating the current cost of replacement and repair for bridge elements is also essential to the success of the BMS projecting sensible projects for the IA DOT to consider for improvement to their bridge network.

The IA DOT has selected Pontis, the most widely used BMS in the nation, to manage their current bridge network (1). This program was developed by FHWA, and is continually being updated. Pontis now allows an agency to customize and utilize the program according to the needs of an agency. The widespread application throughout the nation allows for data sharing between states and enhances the calibration process of the program. Recent developments of the Pontis software also allow for improved modeling of an agency's policy. This strengthens the confidence the agency has in the recommended actions and projects that the BMS generates.

To insure accurate maintenance, rehabilitation or replacement (MR&R) alternatives for an element in a bridge structure, condition of a bridge is no longer separated into large divisions such as bridge deck, superstructure and substructure. The Pontis BMS requires a condition evaluation of each separate element each having up to 5 different states. Each record can include a percentage of the element that is in each condition state.

The IA DOT is currently in the beginning stages of setting up a working database in Pontis. Pontis bridge inspections have been collected for various state bridges since 1996. This data has been loaded into the Pontis database, including inspections through 2003. Although default values are included with the Pontis program, initial customization is desired to assure accurate modeling and project generation by the BMS. These customizations include development of initial:

- Costs : Replacement, Failure, and Maintenance, Repair and Rehabilitation (MR&R)
- Deterioration rates
- Rules : Look-Ahead, Scoping, Major Rehab and Agency Policy

These initial values will provide a foundation for future improvement of the BMS. It is imperative that these initial values are reviewed by the IA DOT to insure that the input is representative of their current actions.

LITERATURE REVIEW

Pontis Implementation

As outlined in Ref. (1), the Pontis Bridge Management System is being utilized throughout the nation. By allowing various agencies the opportunity to share their individual resources, comparisons of the databases allows for more feasible initial development, along with ongoing updating of the database (1). Along with the popularity of the Pontis BMS software, the customization of the program for individual agency use is widespread throughout the nation as well (1).

Although the Pontis software is selected at most state agencies for bridge management, certain issues from the program have arisen. For example, although an array of elements is included in the default setup of the Pontis program, individual agencies may desire expanded element lists. These additional elements may assist inspectors in accurate assessment of bridge condition, or include innovative material not included in the default list. For example, the Iowa DOT sought the development of an element representing the bottom of concrete decks, with similar parameters as other deck elements. This allows assessment of the bottom of the deck separate from that of that of the driving surface. Due to traffic wear, the top of a bridge deck often degrades at a faster rate than that of the deck bottom. Overlay of the deck is an optional solution to spalling problems on the top of deck, but obviously is not a solution for spalling of concrete from the bottom of the deck. These continual developments drive addition of bridge elements into the BMS, and corresponding element parameters must be included. These parameters include a cost set representing the replacement, failure, and MR&R costs, along with deterioration rates and repair

alternatives. Although this process seems tedious, it is necessary to accurately represent the existing bridge elements in an agencies bridge network.

Following the completion of building the element database, further customization is often desired to eliminate problems of unit measure discrepancies. Each element in Pontis is presented with a given unit of measure so that the costs may be presented generally for the element. The default unit of measure is often unsatisfactory to generally describe the cost of the element, or any action done to the element. For example, the unit of measure associated with concrete box girders is a linear measure. A cost must be associated with the replacement of this element, on a basis of length, when the cross-sectional size is of utmost importance in the estimation of cost. Often in initial development, the unit compatibility problem is not completely addressed (2). Therefore, following initial implementation of the Pontis program, more customization of the database would be needed by the agency. This customization could include defining new elements in the database, changing the unit measure of different elements, along with changing the layout and creating new forms and additional applications (1). Changing element unit measure is an especially difficult issue, due to costs and inspection requiring use of identical units. Although changing the units of a concrete box girder to cross-sectional area may benefit the cost estimates, attempting to describe the condition of this element over its length becomes impractical with this unit of measure. Solutions may include expanding the element list, with elements having ranges of element dimensions that are similar in unit cost.

Various methods have been used to implement Pontis into different agencies. Some have chosen to strictly use the default values provided with the program for initial use, and rely on continued inspection and expert opinion to calibrate their database over time. Differences in default database parameters from representative parameters of an agency will result in a BMS that is inaccurate in predicting future project needs due to its lack of resemblance to the agency's environment, element characteristics, and construction practices on bridge maintenance. As outlined in the research by Fanous et al., essential parameters must be accurately estimated for a BMS to be effective early in its use (3). These parameters include level-of-service goals, agency costs and user costs, along with deterioration rates (3). These values must remain representative of the agency for Pontis to recommend projects that are common to there ongoing infrastructure management. This will allow for the transition from traditional maintenance planning to further dependency on Pontis to recommend bridge candidates for work.

Implementation Strategies

Various research throughout the nation has summarized the strategies of implementation of certain parameters in Pontis. From the research of Sobanjo and Thompson, the development of agency costs was completed for Florida's Pontis database (2). Assorted methods were used to determine the final cost values to be used by the Florida DOT (FDOT). A sensitivity study was also carried out to determine the most critical cost elements. It was found that failure unit cost was the most sensitive in the analysis. Also, the discount rate, which represents the loss of value over time, was found to affect the recommendations of the BMS (2). Historical data from the FDOT was utilized to obtain an estimate of present day agency costs, and proved beneficial for 70% of the elements tested. An expert review process was also used to verify the estimated costs from the historical data, and data was then manipulated according to expert recommendation, or used directly for the final results. Experts also provided cost estimates for elements with little or no historical cost information.

Fanous et. al. conducted similar elicitations to obtain agency costs; however, this study contained no baseline or initial estimate of cost from historical data (3). Historical data was only later used as a comparison to the estimates made by experts from the state agency. This method created cost estimates that were sometimes quite variable, not only between expert and historical data, but also among the experts (3). The final values were determined by the judgment of the agency's Bridge Maintenance Engineer.

Deterioration Rates

The study of deterioration on an element level has been an ongoing challenge for those utilizing Pontis. The main requirement for Pontis to calculate this value internally is abundant inspection data with changing condition states. The Iowa DOT currently maintains over 50 structures that were constructed over 50 years ago. With Pontis-style inspections of these bridges beginning less than 10 years prior to implementation, an initial estimate of deterioration rates is essential. Multiple methods for initial deterioration rate estimates have been utilized for various agencies. Certain agencies will use the default values, which stem from a California study (1), (2). Other agencies will conduct a full elicitation study, trying to estimate deterioration from expert opinion (2). A methodology was developed in Louisiana to utilize there State National Bridge Inventory (NBI) data to determine their initial deterioration rates (4), due to the lack of past Pontis-style inspections. However, NBI inspections include rating of only three bridge components, which then must be extrapolated to cover all possible bridge elements in Pontis. Also, NBI inspections are rated on a scale from 0-9, with 9 being the best condition, while the condition states in the

Pontis program are rated on a scale from 1-5, with 1 being the best condition. Therefore, further estimation must be made to merge the condition states together.

OBJECTIVES

The objective of this research is to develop and implement a working Pontis database for the IA DOT. This will include a description of the selected methodology, and the implementation of initial Pontis values. It will include the development of initial replacement and MR&R costs. Additionally, it will include the initial development of element deterioration rates, along with all Pontis Rules and a Policy Matrix. Due to the significance of failure cost in Pontis, this development was completed in a separate research effort.

Although initial development attempts to model the existing policy of the agency, while still providing the most economical project selection, it is imperative that continual updating be completed in the Pontis database to insure improvement to the current bridge network. It must be understood that software with the complexity of Pontis will require both time, and continual data entry to not only improve the reliability of the management recommendations, but also insure evolution of the BMS with the continual changing standards and policies of the agency.

PONTIS IMPLEMENTATION AND CUSTOMIZATION

Overview

As outlined in chapters 4 and 5 of the Pontis User's Manual, a preservation policy can be initialized in Pontis for use in program simulation (5). Although the methodology to collect these values is often left to elicitation over time, the required elements for Pontis simulations are presented. This manual was utilized to update or calibrate the five components in this research; agency replacement costs, agency MR&R costs, deterioration rates, Pontis Rules and a Policy Matrix. After modifying this data, simulations can be completed to verify the performance of the BMS compared to current IA DOT maintenance schedule. It is imperative that the scheduled maintenance of the IA DOT compare well with Pontis simulations to insure confidence in Pontis. As concluded by (1), 50% of the agencies currently using Pontis are only using the program as an inspection database. This represents agency insecurity with the capability of Pontis to effectively manage the bridge network. This also can be attributed to a lack of training on the use of Pontis to recommend projects and maintenance actions for an agency. It is a goal of this research to instill confidence in the IA DOT to utilize Pontis, yet allow the BMS to operate and optimize over time.

Deterioration Model

The Pontis program uses the Markov Chain modeling procedure to predict the future condition of different elements. This model of deterioration correlates a probability of condition change with each condition state. After each cycle, in this case one year, a percentage of the element will transition to the next condition state, and a percentage will remain in the current state. Therefore basic regulations of the model include only transitioning one state during each cycle.

Each element in the Pontis database requires a set of deterioration rates for each possible state. The default rates are based on a California study, which can be used as a baseline, yet are considered to differ from that of Midwest states, due to the different environmental factors. Therefore, the first action was to collect current deterioration rates from surrounding state agencies that are currently utilizing Pontis for their bridge network. These deterioration rates would reflect the environment of the Midwest, and also provide further comparison for any elicitation data from the IA DOT.

State databases that were attained for comparison include Wisconsin and Kansas (6), (7). Illinois also shared their database; however they changed a majority of their element definitions and units of measure (8). Due to this discrepancy, deterioration rates from Illinois were not used in the analysis.

Transition probabilities can be found using Pontis, utilizing historical data alone. Since Pontis inspections have been done in Iowa since 1996, the BMS was used to calculate deterioration rates strictly from the historical data. However, the inspection data was very limited due to some bridges only occasionally being inspected during each cycle. Some bridges have yet to be inspected using the Pontis format, and many others have only received one Pontis style inspection. These bridges offer no insight to the transition of the element over time, since multiple inspections are required for that relationship to be made. Multiple inspections on particular bridges provide a relationship between the condition state of an element and the time between inspections. This results in a deterioration rate that can be related to a transition probability in Pontis. There are limited bridges with sufficient inspection cycles to provide Pontis with sufficient data to develop accurate transition probabilities, therefore Iowa historical data was included in the analysis, but with known limitations of its use.

In discussion with the IA DOT, it was determined that a simple elicitation would prove the most beneficial in the finalization of transition probabilities. Although more complicated elicitations can be conducted to attempt more accuracy, for the initial implementation it was determined that a straightforward analysis would be favorable. More thorough elicitations could have presented a deterioration matrix for each element to be filled out by the specialist. However, due to the Markov Chain concept, the probability of deterioration to the next state is limited to a one year timeframe. Estimating bridge degradation over a single year for any element is largely speculation, and the input required for multiple elements is intimidating for an agency. By expanding the deterioration over a more significant timeframe, the results of the elicitation will become more intuitive to agency specialists.

Two separate forms were created for elicitation from the IA DOT. They were both based on expansion of the Markov Chain models. Deterioration rates for all elements that exist in more than 100 bridges in the state were utilized in the elicitation. Element deterioration was expanded using the Markov Chain, sufficiently enough to produce significant quantities of the element in its worst condition state. The amount of the element in the worst condition state after the first 50 years were summarized in a chart that included results from Iowa historical data, the default values, and the average of the Wisconsin values, Kansas values, and Iowa historical values. A similar chart system was created that included the time in years required for 50% of the element to reach the worst condition. It was expected, due to the lack inspection cycles, that the Iowa DOT historical values would, for certain elements, be unreliable, and be relatively meaningless. However, for other elements with sufficient inspection cycles containing changes in condition state, the estimates proved more dependable. Therefore, all Iowa DOT historical estimates were included, and were to be judged vigilantly.

Figure 1.a shows an example elicitation sheet distributed to the IA DOT with various elements and their corresponding theoretical percent of the element in the worst condition state after the first 50 years of deterioration. Figure 1.b shows an example elicitation sheet with various elements and their corresponding theoretical time in years for 50% of the element to be in the worst condition state. Figure 1.b also includes the average of the expert opinions, which was included on all charts following the completion of the forms, to assist in the analysis of the findings.

The expert elicitations were completed by three personnel from the IA DOT that represented inspection, design and maintenance experience. The results of the elicitations correlated most closely with the average of Wisconsin, Kansas and Iowa historical data. The expert opinion of the IA DOT typically suggested faster deterioration of superstructure elements when compared to that of the average of Wisconsin, Kansas and Iowa historical data. However, expert opinion suggested slower deterioration of substructure elements when compared to that of the average of Wisconsin, Kansas and Iowa historical data.

When the difference in time to reach 50% in the worst condition state exceeded 50 years, additional analysis was done for the finalization of the transition probabilities. If the difference was less than 50 years, the average of Wisconsin, Kansas and Iowa historical data was chosen as an acceptable estimate for initial implementation. It was found that of the 32 elements in the elicitation, only 6 elements qualified for further analysis. Elicitations of these 6 elements were reanalyzed to determine if outlying elicitation estimates was causing the discrepancy. Of the six, four were determined to contain an outlying estimate from one expert with respect to other elicitation values. Once the outlying estimate was removed, the values correlated very closely with the average of Wisconsin, Kansas and Iowa historical data once again. The remaining two elements were adjusted by averaging the elicitation results with the average of Wisconsin, Kansas and Iowa historical data. Interestingly, the remaining two elements had little effect on bridges or bridge performance, concrete culvert and aluminum railing. Therefore adjustment techniques were simplified, due to the lack of bridge network importance.

To adjust element values, the transition probabilities must be changed to reflect the extrapolated Markov Chain value. With up to 5 condition states for each element, any transition probability in any state can be adjusted to correlate to the desired value. It was found through study that the extrapolated values were very sensitive to small changes in the deterioration rates. To adjust these elements it was found to require less than one percent change in any one condition to obtain the desired result.

Replacement Costs

In order to estimate the replacement costs of elements, economic factors for the agency must be considered. The default values in Pontis stem from a study conducted at Clemson University, which represent the regional costs to replace various elements in there specific region. A Midwest state, such as Iowa, has different costs associated with the replacement of elements due to the availability of materials, the cost of labor, along with additional economic factors for the specific region.

The IA DOT Office of Contracts keeps current records for all bridge bid items, and their associated awarded contract prices. Following each fiscal year, a Summary of Awarded Contract Prices is released for each of the bid items that were used during that year (9). This summary includes the low, high, and average cost per unit

that was charged from the winning bidder on each project in the state. This data is a direct representation of what the state would expect to pay for replacement of elements in their current bridge network. However, discrepancies arise when attempting to relate bid items used by the IA DOT, and element definitions from Pontis. Another difficulty is the unit compatibility issue. Many elements are measured differently within Pontis than the measures used by the IA DOT, along with other state agencies. For these particular elements, estimates were made to convert element prices to different units of measure. These estimates stemmed from quantities from bridges that were deemed representative of an average bridge in Iowa containing the needed elements.

For elements without reasonable unit convertibility, or elements not included in the Summary of Awarded Contract Prices, an elicitation to the DOT was made. This elicitation also included cost values from Kansas, Wisconsin, Florida, and the default values stemming from a study in California. With this information, costs were developed by the DOT to represent their experience with bridge element replacement. Elements not used by the IA DOT were left at the default value levels. Table 1 summarizes the results of the replacement cost generation.

Policy Matrix

The Policy Matrix is a summary of various design values including roadway widths, load allowances, and vertical clearances. These values are divided into two categories; legal limits and desired design values. Once a policy set is established, a bridge's configuration and load capacity can be compared to the legal and design limits. Deficiencies of the bridge are easily identified, and improvement projects can be considered. Improvement projects are separated from preservation actions in Pontis. Preservation actions simply maintain or restore the physical condition of the bridge, whereas improvement projects seek to improve the bridges functionality. Improvement projects are analyzed separately, yet are chosen on the same benefit/cost rational as maintenance projects.

It is imperative that the Policy Matrix reflect the current standards of the agency. Therefore, no comparisons were made to other states, or to the default values. A meeting with various engineers from the IA DOT was scheduled to attain the appropriate current design and legal standards for the State of Iowa. Representatives from the Methods Office, which is responsible for developing all of the design standards, details and policies for Iowa's roadways, were present in the meeting. A representative from the Office of Bridges and Structures provided additional experience with specific bridge related issues. Further study was completed by contacting the Statewide Urban Design and Specifications group to ensure all roadway dimensions were collected.

Pontis Rules

Rules were recently introduced to the Pontis software to assist agencies to develop practical projects. Separating a bridge into discrete elements allows for a better assessment of the condition. However, when bridge repair is done, economical factors arise that cannot be interpreted directly by the program, which often resulted in projects that were not feasible. It is imperative to identify elements that are interdependent on each other, and insure that if one element is repaired, the dependant element is also considered for repair. Also, if a bridge is scheduled for replacement or major rehabilitation in the near future, continuing maintenance on the bridge will be considered unwise by the agency. These common issues in planning have been addressed by the Pontis Rules. Rules are separated into four main categories; Scope Rules, Rehab Rules, Look-Ahead Rules, and Agency Policy Rules.

Scope Rules are used to build more complete projects including various elements. If a bridge deck is scheduled to be replaced, the joints will also need to be replaced, and therefore included in the cost estimate and work proposal. The scope rules are designed to assist in considering elements that are interdependent on each other in the project planning process.

Rehab Rules are based on the overall health index of the bridge, which includes an assessment of the condition of all of the elements in the bridge. If the health index is below a certain value, structural actions, such as replacement or rehabilitation, will be recommended.

Look-Ahead Rules are designed to prevent continual maintenance to bridges that are soon scheduled for major rehabilitation or replacement. With limited funds to support major bridge work, it is unfeasible to allow maintenance on bridges that are scheduled for replacement within five years. Therefore if/then statements are utilized in Pontis to discourage the recommendation of smaller maintenance projects, when it is known that more major work is scheduled for the near future.

Agency Policy Rules allow an agency to direct the Pontis software in creating suggested projects that resemble there current practice in maintenance. This may deter optimal economic alternatives from the Pontis software, yet will account for factors that Pontis cannot interpret. Although a percentage of a given element may validate repair, it often is easier to complete maintenance on the entire element, no matter the condition. If a section of concrete deck requires overlaying, it is sensible to overlay the entire deck to ensure a smooth surface and to eliminate further deterioration of other sections of the deck. If a steel element requires partial painting, it is rational

to paint the entire element to prevent future painting needs on that element. Often, the mobilization and traffic control of a maintenance project exceeds the cost of the maintenance work itself, therefore it is vital to utilize each project, and prevent repetitive maintenance recommendations to the same bridge structure.

The Pontis software requires no rules to create recommended projects; however default rules are included in the software. It was determined that the default rules would be combined with the current rules being used by surrounding states. This elicitation form would outline possible rules that could be utilized in the IA DOT database to assist in the project planning. Example elicitation forms that were completed by the IA DOT are shown in Figures 2-4. The form allowed the IA DOT to develop a sense of the purpose of the rules, and also allowed for additional recommendations if the listed rules were insufficient in representing the current policy of the IA DOT.

Of the 14 example Scope Rules, 5 were chosen to represent the IA DOT policy. The Rehab and Agency Policy Rules were both accepted as representative of current standards that the agency currently follows. Of the 23 example Look-Ahead Rules, 19 were adopted by the IA DOT. No additional rules were recommended by the IA DOT for the initial implementation; however the current rule set can be easily modified to better serve the agency needs over time.

Maintenance, Repair and Rehabilitation (MR&R) Costs

The MR&R cost evaluation was left as the final task in the implementation of a working database into the IA DOT. The IA DOT has completed minimal element level maintenance and repair on its current infrastructure. Although numerous bridges have received deck replacements, and painting to girders, estimates could not be made on the numerous different actions on each discrete element. Therefore, elicitations were determined to be ineffective in determining the costs of repair on the current infrastructure. A sensitivity study was conducted by Sobanjo and Thompson, outlining the MR&R costs limited sensitivity to changes in recommended actions (2). Each element maintenance cost was adjusted from the default value by 50, 75, 125, and 150% to determine the effects on the recommended actions. It was found that less than 20% of the elements changed their recommended actions, even after increasing the maintenance cost by 150%. This sensitivity analysis was conducted with all other cost parameters in Pontis being held constant at the default value. For the IA DOT implementation, many parameters within Pontis were already finalized. Therefore, it was determined that a simplified sensitivity analysis would be conducted with the current replacement costs and deterioration rates, to assess the current sensitivity of MR&R costs in the updated database. This was also used to assess the change in similarity with the programmed candidates from the IA DOT.

A $\pm 25\%$ change in MR&R costs was completed on all elements that are being used in at least 100 bridges in the IA DOT infrastructure. Identical simulations were then run to assess the changes in recommended projects, and the actions of chosen projects.

Simulation Results

To assess the effectiveness of the initial implementation, a list of structures in the five year planning program from the IA DOT was attained. This is generated by BRIDGE CAN, the current software utilized by the agency for project selection. It is clear that projects generated from the Pontis software, which utilizes mathematical methods to ensure economical efficiency, will not coincide directly with that of the current tracking software used by the IA DOT that attains its projects from various engineers throughout the state. However, similarity in bridge selection is imperative for agency confidence in the Pontis software.

Following both simulations, comparisons were made to the IA DOT output. The first simulation was completed after increasing the MR&R costs of the most used elements by 25% from the default values. Pontis recommended 156 bridges for various repair and replacement, 53 of which coincided with bridges selected by the IA DOT in their planning program. The second simulation was completed after decreasing the MR&R costs of the most used elements by 25% from the default values. Pontis recommended 119 bridges for various repair and replacement, 48 of which coincided with bridges selected by the IA DOT in their planning program.

It is intuitive that as MR&R costs decrease, more projects could be recommended by Pontis. However, as MR&R costs decrease, additional actions become more beneficial in Pontis, therefore the projects selected by Pontis grow in complexity, creating a higher cost project, yet theoretically more beneficial to the user.

Although various bridges were chosen for work by both Pontis and the IA DOT, the work recommended by Pontis was most often repair and rehabilitation, when the IA DOT programmed mostly replacement projects. Of the over 135 million dollars allocated for bridge projects by the IA DOT, 74% was issued to bridge replacement projects. This is evidence of the difference in the maintenance policy of Pontis compared to that of the IA DOT. As MR&R costs increase, small repair projects become less feasible for the given benefit to the user. This causes replacement to become somewhat more feasible, which results in a database that would more closely represent the current practice of the IA DOT maintenance strategy.

The percent of projects recommended by Pontis that correlated to a planned project from the IA DOT was calculated. These match rates were found to differ only by 6% between the two simulations, proving the limited sensitivity of the MR&R costs when all other parameters are held constant. Many similarities were found between both simulation results. Pontis consistently recommends projects to be done earlier than the scheduled date by the IA DOT. Also, the bridges that were recommended by Pontis for replacement were the exact same in each simulation. The MR&R costs proved to be insensitive in the updated database, not only to recommended action, but also recommended year for the actions to be completed. It was therefore determined that the default MR&R costs were acceptable for initial implementation of Pontis. If individual actions are determined by the IA DOT to be unreasonable, and causing unreliable recommendations, changes to the maintenance costs can easily be made through an elicitation process described in the Pontis User Manual (5).

CONCLUSIONS

The completed research provides a basis for initial implementation of a Pontis database for an agency with limited historical data. With a greater number of Pontis inspections, more confidence can be placed on the historical data to produce realistic transition probabilities. The development of the replacement costs for this research was highly dependant on the current price reports collected by the IA DOT. Without such information, a more complete elicitation would be required or additional surrounding state databases for comparison. The Pontis Rules are not essential for the success of the Pontis database to function, therefore could be considered unreasonable for initial implementation. However, it was felt necessary in this research to develop an applicable rule set to ensure a level of confidence in the Pontis software that would spur further use and development of the database. The Policy Matrix was developed directly from current standards that the agency utilizes in current designs. A state agency, such as the IA DOT, is continually updating design methods to ensure safety to the public. As these changes are made in design, the Policy Matrix can be easily modified to accommodate such changes.

It is clear that Pontis will be unable to recommend identical projects and actions matching the current planned projects in the IA DOT, which stem from recommendations of engineers. The results of Pontis are meant as a guide for management of the current bridge network, which relies on economical analysis to distribute the limited funds of an agency. Careful examination of the recommended actions must be completed to insure reasonable projects. It must also be noted that continual updating of the database will not necessarily converge on the typical maintenance strategy of the IA DOT. However, with proper updating of the Pontis database, funds will be utilized more efficiently, and the condition of the bridge network will be improved.

RECOMMENDATIONS

An agency's current training and experience with Pontis must be considered in the implementation process. With Pontis software continually being updated, corresponding implementation and training strategies have been improved and expanded to assist in the accuracy of the bridge management process. As agencies begin implementation at different stages of historical data collection and Pontis inspections, different implementation strategies may become more beneficial. From the completed research, basic parameters could be identified and implemented with the IA DOT requiring minimal background in the Pontis software. As various agencies across the nation continue in their use of Pontis, sharing of database parameters will become more accurate and beneficial to agencies.

Recommendations for initial implementation of a working Pontis database are as follows:

- **Surrounding agency databases should be collected and assessed to insure correspondence with the given agency.** Surrounding state agency databases were vital in the implementation process for the IA DOT. These databases provided parameters that could be compared to expert opinion, and contained customization examples that assisted in the development of specific modification desired by the IA DOT.
- **Contribution from agency engineers should be utilized when possible to instill confidence with the Pontis software.** By allowing input and opinion from the agency, collection of agency specific parameters could be attained and implemented promptly. Due to the agency providing project planning information, analysis of the practicality of Pontis recommended projects and actions was easily completed.
- **Simplified elicitation forms can be utilized when experience with Markov Chain modeling is limited within the agency.** Bridge elements often have a design life reaching over 100 years. Deterioration of these elements is often difficult to assess in a matrix format, such as required by a Markov Chain. However, by providing experienced engineers with manageable concepts in the deterioration of bridge elements, an estimate can be made on the overall deterioration of that element.

- **Pontis simulation results should be compared to current project planning of the agency to insure an association with current practices.** Although results of this research proved a difference in the maintenance strategy of Pontis when compared to the IA DOT, a relationship was evident in the structures that require attention. This will allow the IA DOT to begin using Pontis as a bridge management tool, and not only as an inspection database.
- **Continual accurate inspection entry and updating to the database is vital to the success of Pontis as a bridge management tool.** As inspections are added, additional bridge elements will experience sufficient condition state transitions to more accurately assess the deterioration of the element. Continual historical data collection will assist in the accuracy of all agency cost values, and updating of Pontis parameters will insure the ability of Pontis to make economical recommendations in bridge management.

REFERENCES

1. Robert, W. E., Marshall, A. R., Shepard, R. W., Aldayuz, J. (2003) "Pontis Bridge Management System: State of the Practice in Implementation and Development" *Transportation Research Circular, 9th International Bridge Management Conference*, April, 2003, 49-60.
2. Sobanjo, J. O., Thompson, P. D. (2001). "Development of Agency Maintenance, Repair and Rehabilitation (MR&R) cost data for Florida's bridge management system" Final Report, Florida Department of Transportation, Tallahassee, Florida.
3. Fanous, F., et. al., (1991). "Essential parameters for an Iowa bridge management system" Report submitted to the Midwest Transportation Center, Ames, Iowa.
4. Zhang, Z., Sun, X., Wang, X. (2003). "Determination of Bridge Deterioration Matrices with State National Bridge Inventory Data" *Transportation Research Circular, 9th International Bridge Management Conference*, April, 2003, 207-218.
5. Cambridge Systematics, Inc. *Pontis Release 4 User's Manual*. AASHTO, Washington, D.C., 2001
6. Kansas Department of Transportation Pontis Database, 2003
7. Wisconsin Department of Transportation Pontis Database, 2003
8. Illinois Department of Transportation Pontis Database, 2003
9. Summary of Awarded Contract Prices, Iowa Department of Transportation Office of Contracts, 2001

List of Tables

Table 1 Iowa DOT Replacement Cost Estimates

List of Figures

Figure 1 Example deterioration elicitation sheets.

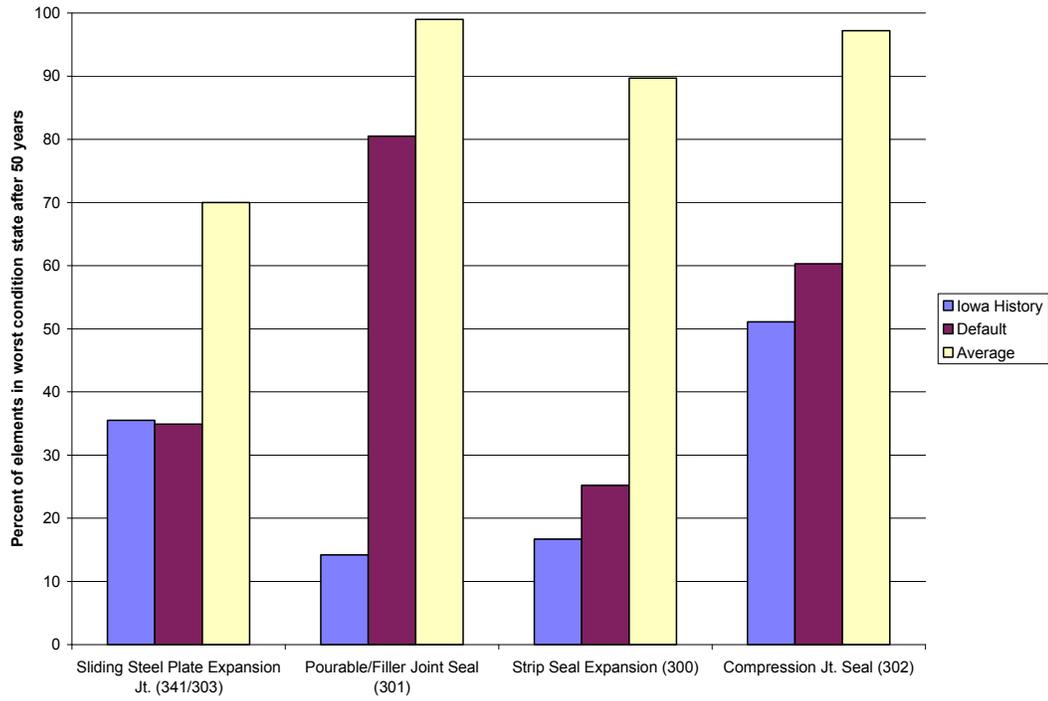
Figure 2 Scope and Rehab Rule elicitation form.

Figure 3 Look-Ahead Rule elicitation form.

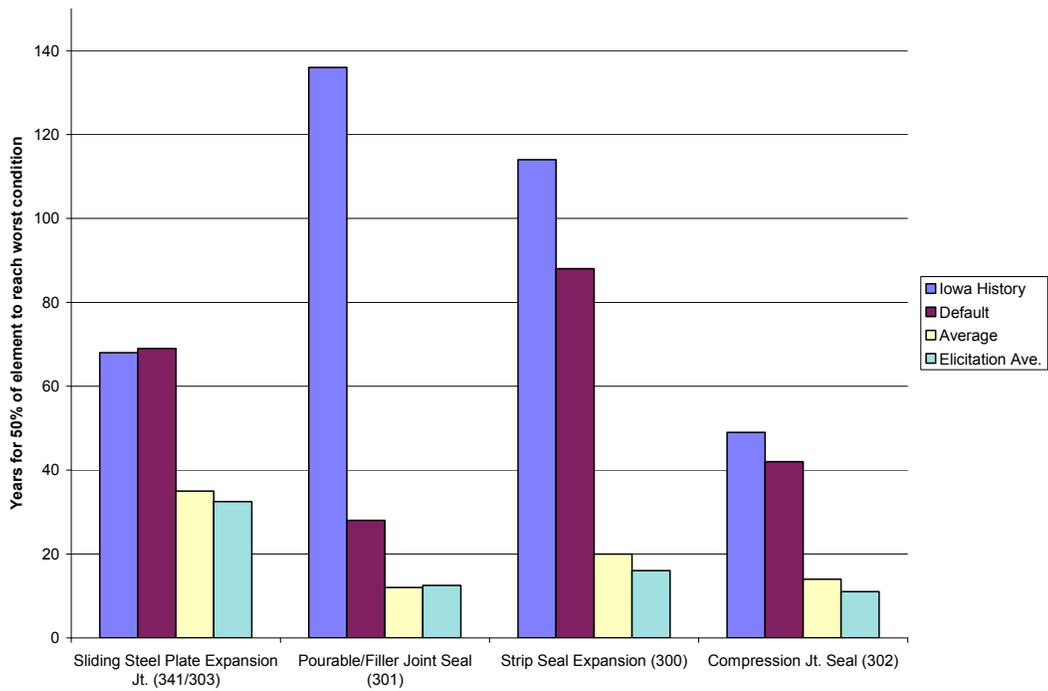
Figure 4 Agency Policy Rule elicitation form.

TABLE 1 Iowa DOT Replacement Cost Estimates

Element #	Elem. Description	Unit of Measure	2003 Iowa D.O.T. English Unit
12	Bare Concrete Deck	m ² / S.F.	\$11
13	Unprotected Conc Deck w/Asphalt Overlay	m ² / S.F.	\$12
22	Conc Deck w/ Rigid Overlay	m ² / S.F.	\$14
26	Conc Deck w/ Coated Bars	m ² / S.F.	\$11
27	Conc Deck w/ Cathodic Protection	m ² / S.F.	
28	Steel Deck w/ Open Grid	m ² / S.F.	\$33
31	Timber Deck (bare)	m ² / S.F.	
38	Concrete Slab (Unprotected)	m ² / S.F.	\$28
39	Unprotected Concrete Slab w/ Asphalt Overlay	m ² / S.F.	\$29
48	Protected Conc. Slab w/ Rigid Overlay	m ² / S.F.	\$31
52	Conc. Slab w/ Coated Bars	m ² / S.F.	\$29
53	Conc. Slab w/ Cathodic Protection	m ² / S.F.	
54	Timber Slab	m ² / S.F.	
105	R/C Box Girder	m / L.F.	\$3,000
106	Unpainted Steel Open Girder	m / L.F.	\$562
107	Painted Steel Open Girder	m / L.F.	\$562
109	Pre-Cast Open Girder	m / L.F.	\$129
110	R/C Open Girder	m / L.F.	\$129
111	Timber Open Girder	m / L.F.	\$300
113	Painted Steel Stringer	m / L.F.	\$129
117	Timber Stringer	m / L.F.	\$60
121	Painted Steel Bottom Chord Through Truss	m / L.F.	
126	Painted Steel Through Truss excluding Bottom Chord	m / L.F.	
131	Painted Steel Deck Truss	m / L.F.	
141	Painted Steel Arch	m / L.F.	
152	Painted Steel Floorbeam	m / L.F.	
156	Timber Floorbeam	m / L.F.	
161	Painted Steel Pin &/or Pin-Hanger Assembly	each	\$5,000
202	Painted Steel Column or Pile Extension	each	\$1,607
204	P/S Conc. Column or Pile Extension	each	\$1,714
205	R/C Column or Pile Extension	each	\$2,772
206	Timber Column or Pile Extension	each	\$1,157
210	R/C Pier Wall	m / L.F.	\$1,168
215	R/C Abutment	m / L.F.	\$1,500
216	Timber Abutment	m / L.F.	
231	Painted Steel Abutment Cap	m / L.F.	
234	R/C Pier Cap	m / L.F.	\$2,100
235	Timber Pier Cap	m / L.F.	\$200
240	Unpainted Steel Culvert	m / L.F.	\$139
241	Reinforced Concrete Culvert	m / L.F.	\$536
300	Strip Seal Expansion Jt.	m / L.F.	\$200
301	Pourable Joint Seal	m / L.F.	\$75
302	Compression Joint Seal	m / L.F.	\$150
303	Assembly Joint/Seal (modular)	m / L.F.	\$1,000
304	Open Expansion Jt.	m / L.F.	\$200
310	Elastomeric Bearing	each	\$500
311	Movable Bearing	each	\$1,500
313	Fixed Bearing	each	\$1,500
314	Pot Bearing	each	\$2,000
315	Disk Bearing	each	
321	Concrete Approach Slab	each	\$5,713
331	R/C Conc. Bridge Railing	m / L.F.	\$54
332	Timber Bridge Railing	m / L.F.	\$35
333	Other Bridge Railing	m / L.F.	\$112
335	Steel Bridge Railing	m / L.F.	\$48
357	Pack Rust	each	none
358	Deck Cracking	each	none
359	Bottom of Deck, Slab, or Box Cracking	each	none
361	Scour	each	none
362	Traffic Damage	each	none
365	Steel - Fatigue Cracks	each	none



a. Percent of element in worst condition state elicitation form.



b. Years for 50% of elements to reach worst condition state completed elicitation form.

FIGURE 1 Example deterioration elicitation sheets.

Scope Rules

Used to build more sensible projects that are cost effective.

Put a **check** next to all additional actions that the IA DOT would do along with the given major action.

If there is an additional action that should be done that is not listed, please write it in.

Major Action	Additional Action that could be done
Rehabilitation of Deck	<input type="checkbox"/> Replace joints <input type="checkbox"/> Rehab. Railings & Barriers
Deck Replacement	<input type="checkbox"/> Replace Railing <input type="checkbox"/> Replace Joints <input type="checkbox"/> Replace Approaches <input type="checkbox"/> Replace Keyways
Overlay Deck	<input type="checkbox"/> Replace Joints <input type="checkbox"/> Overlay Approaches <input type="checkbox"/> Rehab. Railing <input type="checkbox"/> Replace Keyway
Repainting Structural Steel	<input type="checkbox"/> Rehab. Bearings
Rehabilitation of Superstructure	<input type="checkbox"/> Rehab. Bearings
Replacement of Superstructure	<input type="checkbox"/> Replace Bearings
Replacement of Keyway	<input type="checkbox"/> Overlay Decks and Slabs

Rehab Rules

Based on Health Index, which is calculated from Pontis using the condition of each element in a bridge. (100% is bridge in perfect condition)

If the Health Index of a Bridge was less than _____%, we would **Replace** the Structure. (Default =50%)

If the Health Index of a Bridge was less than _____%, we would **Rehabilitate** the Structure. (Default =75%)

FIGURE 2 Scope and Rehab Rule elicitation form.

Look-Ahead Rules

Look-Ahead is used to prevent Pontis from recommending rehabilitation actions to a bridge that will soon be replaced, or have a major component replaced. Remember that Pontis can project it's projects into the future to recognize needed bridge replacemen

If the **Structure** is programmed to be replaced within 5 years, **don't** do the following actions to the bridge

	Agree	Disagree
Painting of any element		
Maintenance & Repair of Superstructure		
Maintenance & Repair of Substructure		
Maintenance & Repair of Joints		
Maintenance & Repair of Bearings		
Maintenance & Repair of Decks/Slabs		
Rehabilitation of Superstructure		
Rehabilitation of Substructure		
Rehabilitation of Joints		
Rehabilitation of Bearings		
Rehabilitation of Decks/Slabs		

If the **Substructure** is programmed to be replaced within 5 years, **don't** do the following actions to the bridge

	Agree	Disagree
Maintenance & Repair of Substructure		
Painting of Substructure		
Rehabilitation of Substructure		

If the **Superstructure** is programmed to be replaced within 5 years, **don't** do the following actions to the bridge

	Agree	Disagree
Maintenance & Repair of Superstructure		
Painting of Superstructure		
Rehabilitation of Superstructure		

If the **Painting** of the bridge is programmed within 5 years, **don't** do the following actions to the bridge

	Agree	Disagree
Painting of any element		

If **Deck Replacement** is programmed within 5 years, **don't** do the following actions to the bridge

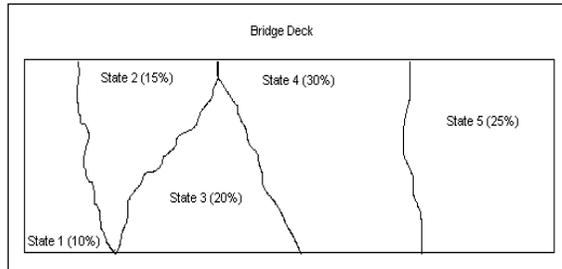
	Agree	Disagree
Rehabilitation of Joints		
Maint. And Repair of Railings		
Rehabilitation of Railings		
Painting of Railing		
Rehabilitation of Deck		

FIGURE 3 Look-Ahead Rule elicitation form.

Agency Policy Rules

Used to implement a specific department's policies on bridge rehabilitation. These rules will limit the ability of Pontis to recommend projects that result in the least long-term cost, or highest B/C ratio. This is due to the user defining what actions

For each element, different states can exist at the same time. Below is a bridge deck with a different percentage of the area assigned to each state. The agency policy rules determine what action the Iowa DOT would do for each condition state, condition



The chart shown below is entered into Pontis, and a priority number is assigned to each grouping. Below it shows the their are 4 different criteria for Deck/Slabs, and each would be assigned a priority number. This number would tell Pontis to check the

The above bridge deck would have 75% in State 3 or greater, 55% in State 4 or greater and 25% in State 5. Therefore ALL of the Deck/Slab criteria apply, so then it would be decided in order of priority.

Chart Directions: The first entry states: If the Deck or Slab has more than 10% in state 4 or worse, than do the following actions for each given state. It is easiest to start from the worst state, and work your way to the left. For example, if you are

Element	Quantity	State	Actions				
			State 1	State 2	State 3	State 4	State 5
Decks/Slabs	>10%	>=4	Overlay	Overlay	Overlay	Patch & Overlay	Patch & Overlay
Decks/Slabs	>15%	>=5	Replace Elem.	Replace Elem.	Replace Elem.	Replace Elem.	Replace Elem.
Decks/Slabs	>20%	>=4	Replace Elem.	Replace Elem.	Replace Elem.	Replace Elem.	Replace Elem.
Decks/Slabs	>50%	>=3	Overlay	Overlay	Overlay	Patch & Overlay	Patch & Overlay
Keyway	>50%	>=3	Replace Elem.	Replace Elem.	Replace Elem.	Replace Elem.	Replace Elem.
Unpainted Steel Below Joint	>50%	>=2	Replace Paint System	Replace Paint System	Replace Paint System	Replace Paint System	N.A.
Steel Below Joint	>50%	>=3	Replace Paint System	Replace Paint System	Replace Paint System	Replace Paint System	Replace Paint System
Unpainted Steel Bottom	>10%	>=3	Replace Paint System	Replace Paint System	Replace Paint System	Replace Paint System	N.A.
Lower Cord Truss	>10%	>=4	Replace Paint System	Replace Paint System	Replace Paint System	Replace Paint System	Replace Paint System
Moveable Steel Bearing	>25%	>=3	Replace Elem.	Replace Elem.	Replace Elem.	N.A.	N.A.
Moveable Steel Bearing	>50%	>=2	Replace Paint System	Replace Paint System	Replace Paint System	N.A.	N.A.
Girders/Stringers/Beams	>20%	>=4	Replace Super (flex)	Replace Super (flex)	Replace Super (flex)	Replace Super (flex)	N.A.
Joints w/ 3 Condition States	>50%	>=2	Replace Joints (flex)	Replace Joints (flex)	Replace Joints (flex)	N.A.	N.A.
Joints w/ 4 Condition States	>50%	>=3	Replace Joints (flex)	Replace Joints (flex)	Replace Joints (flex)	Replace Joints (flex)	N.A.

FIGURE 4 Agency Policy Rule elicitation form.