FINAL CONTRACT REPORT

MODERNIZING BRIDGE SAFETY INSPECTION WITH PROCESS IMPROVEMENT AND DIGITAL ASSISTANCE

Thomas H. Mills III
Associate Professor

Ronald R. Wakefield
Professor

Virginia Polytechnic Institute& State University

Project Manager
William H. Bushman, P.E., Virginia Transportation Research Council

Contract Research Sponsored by the
Virginia Transportation Research Council

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

Charlottesville, Virginia

January 2004
VTRC 04-CR6

NOTICE

The project that is the subject of this report was done under contract for the Virginia Department of Transportation, Virginia Transportation Research Council. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Each contract report is peer reviewed and accepted for publication by Research Council staff with expertise in related technical areas. Final editing and proofreading of the report are performed by the contractor.

ABSTRACT

This research effort was developed to record and analyze the Virginia Department of Transportation (VDOT) bridge/structure inspection processes as an aid to modernizing and automating these inspection processes through the use of mobile personal computer (PC) devices such as Palm/PPCs and other wearable computing devices. The research was conducted using an informal conversational interview process coupled with direct observations to match the perceived processes with actual processes. Once the interviews and observations were completed, work flows were mapped and analyzed for operational bottlenecks and process improvement opportunities. The results of the mappings and a comprehensive literature review were used to analyze the existing work processes. New process transformation maps were created and overlaid on current mappings to complete a transformation model.

Redundancies were observed in the reporting function and bottlenecks were identified within the inspection management and inspection functions. The research also indicates that the inspection process is readily transformable from one that relies on marking up paper reports in the field and then returning to the office for semi-manual reporting to one that is electronically assisted in areas of data capture, automated bridge inventory updates, and semi-automated report production. From this analysis a series of strategies and recommendations were made to assist VDOT in modernizing and transforming their current bridge inspection processes to more efficient digitally assisted processes.

INTRODUCTION

Transportation infrastructure maintenance and improvement in Virginia cost hundreds of millions of dollars annually. Integral to an adequate highway infrastructure maintenance program is timely inspections of the State's approximately 14,000 bridges and several thousand culverts (www.nationalbridgeinventory.com, 2003). Each of these bridges requires periodic inspection. These inspections, ranging from a monthly cycle to once every four years, are done by a limited pool of trained inspectors. As a result there is considerable strain on a physical inspection process that performs 7,000 -10,000 bridge safety inspections annually.

It is conceivable that inspectors spend as much time on administration and travel as they do on actual inspections. Within VDOT there is awareness that adequately defined and mapped inspection processes can facilitate modernization of these same processes. Included within this awareness is the belief that mobile handheld or wearable computers can assist in automating the process and will eventually be an integral part of the entire inspection process. Any study of bridge safety inspection with the intent to modernize processes must consider business practices and workflow processes that:

- Support a safe highway infrastructure.
- Allows inspectors to be more effective in reporting their observations.
- Improve the efficiency, timeliness and accuracy of the inspection process.
- Support the ease and efficiency of communications between recorders and users of the inspection results.
- Facilitate easy acquisition, transfer, archiving, querying, and distribution of pertinent information within the inspection process.
- Support portability of information collected at remote field locations.

For purposes of this report the terms "bridge" and "structure" are used interchangeably and are intended to be representative of both, bridges and culverts. The term "mobile computing" and "mobile computers" specially refers to handheld Palm/Pocket PC's (PPC) or other types of personally worn computers.

PURPOSE AND SCOPE

The broad objective of this research was to investigate and report the means, methodologies, and inherent processes and procedures available for modernizing of the bridge inspection process. The research was intended to provide insights into alternative inspection techniques and mobile computers that could lead to faster inspection turnarounds, higher quality observations, easier retrieval of inspection data, and a more efficient information and communication exchange within the inspection process. From the research a determination can be made that mobile computers can enhance bridge inspections.

The scope of this work was limited to the work practices of field inspectors in field related processes of inspection management, bridge inspection, and conditions reporting. Therefore, this research limits its focus to information management in the bridge safety inspection process,

specifically how field inspections are managed, how the data is collected in the field, and how the data is transcribed, reported, distributed, and archived within VDOT.

The formal areas of exploration involved:

1. information acquisition, i.e., the means, methods and media for field data collection;
2. information transfer; i.e., report preparation, assembly, communications, distribution and archival structures;
3. report communication, dissemination and retrieval, as they relate to field inspection processes;
4. the ability to improve inspections using mobile computers.

The specific objectives of the research were to:

- Map the existing work profiles of a select sample of VDOT bridge inspectors,
- Develop logically linked information maps of the inspection processes,
- Develop process maps of what is possible using information technology (IT) and mobile computers,
- Identify ways of adding value to the inspector's work using IT and mobile computers.
- Provide recommendations for implementation and continuation of the research.

METHODOLOGY

The basic research was conducted using both informal conversation interviews and direct observation techniques. Bridge inspectors from four districts, Hampton Roads, Staunton, Lynchburg, and Salem were interviewed and then observed in their work environments. Each inspector was individually interviewed and asked to describe the current processes they use to perform "routine" bridge inspection. A "routine inspection" is defined by National Bridge Inspection Standards (NBIS) as "a regularly scheduled, intermediate level inspection consisting of sufficient observations and/or measurements to determine the physical and functional condition of the bridge, to identify any developing problems and/or change from inventory or previously recorded conditions and to ensure that the structure continues to satisfy present service requirements (NBIS 23, 2002). As the processes were verbalized they were recorded on "Post-It Notes" and arranged in a sequential order as defined by the inspector. The "Post- It Note" work flows were captured and transferred into four process flow charts, one chart per District. The completed charts were sent for review by each inspector and adjustments and corrections were made.

Each inspection team was then visited for the purpose of observing ("shadowed" through a complete inspection process) and documenting their actual work processes. Once the processes were validated by field observations they were used to revise the work flow charts by incorporating the actual processes. The new work flow charts were then analyzed for process inefficiencies and/or bottlenecks that could be improved through mobile computing. A literature review was conducted simultaneous with the work flow analysis to identify state of the art bridge/structure inspection practices.

The basic informational components of Virginia's Bridge Management System (BMS) as it applies to field inspections are presented next. This review is followed by discussions and analysis of the work processes including innovative mobile computing technologies that may eventuate as part of VDOT's inspection process. The report closes by offering transformation strategies in support of modernizing Virginia's bridge inspection procedures.

RESULTS

Bridge Inspection Informational Components

Bridge Management System

At the heart of any bridge management program are its inspectors. Without well-trained inspectors, a record of the state's bridge inventory and its condition would either not exist or would provide little useful information. VDOT's BMS is similar to BMS's in many other states. It tracks the condition of bridges over time and serves to establish maintenance policies and project plans; it helps to analyze budget data and it assists in developing maintenance and repair recommendations. The primary objective of any BMS is to make the best use of available funds in an overall bridge maintenance, rehabilitation and replacement (MR&R) program while maintaining a bridge infrastructure that's safe for public usage. Without regular maintenance, the overall condition of a bridge deteriorates over time. Therefore, a BMS must utilize accurate and accessible inspection information to predict a bridge's structural conditions.

Bridge information in Virginia is combined and accessible within two distinct databases: Highway Traffic Records Information System (HTRIS), and Pontis. These two databases help the state meets its obligation for compliance with federal laws and with the NBIS. Additionally field inspectors prepare Structure Inspection Reports (SIR) composed of written commentary, deterioration quantities, graphical data, and photographs compiled from their observations.

In order to satisfy federal reporting requirements it is essential that reported observations use a common baseline to identify the condition levels as a bridge deteriorates. Virginia provides standardized training for all inspectors through a comprehensive training course based on the Federal Highway Administration's (FHWA) "Bridge Inspector's Training Manual" and NBIS. This commonality in training is intended to standardize the process by minimizing the variability in inspection observations and reports.

National Bridge Inspection Program

To be eligible for federal highway funds the FHWA mandates that each state establish a methodology to inspect and report bridge deterioration in compliance with the NBIS. The National Bridge Inspection Program is a component of the FHWA that develops and assists states in managing their transportation infrastructure. Major components of the National Bridge Inspection Program are the development of NBIS and maintenance of a National Bridge Inventory (NBI) database. Information on more than 600,000 bridges, including 13,000 in Virginia, resides within this database.

The FHWA through the NBIS requires all states to conduct bi-annual inspections of all bridges greater than 20 feet in length that are located on public roads. All bridges in the state's inventory that meet this criterion must be inspected and any deterioration or other changes in condition must be reported in conformance with NBIS. The data is then used to determine quantity, condition and funding eligibility for a state's bridge and structure inventory. The inspection results must be recorded on standard forms for submission by the state for inclusion in the NBI (NBIS 23, 2002). Other state standards may require a more frequent inspection of the states bridge/structure inventory. Collectively, HTRIS, Pontis and SIR form the backbone of informational support and inspection data for Virginia's BMS.

Highway Traffic Records Information System (HTRIS)

The HTRIS database is used as a centralized inventory system to maintain detailed records on the state's roads, bridges, and culverts. HTRIS data is used to supply asset information for inclusion in the NBI. The interaction of HTRIS with NBI was not explored in this research.

HTRIS is VDOT specific and is maintained in a stand-alone pre-windows operating system format. All critical bridge inventory data is maintained in 178 separate fields. Among the data fields within HTRIS are sufficiency ratings, geometrical data, structure and material type, load ratings, service and age, date and frequency of inspection, etc. All newly constructed bridges are entered into this database and updated thereafter upon completion of each inspection. Much of the data that resides within HTRIS can be incorporated into Pontis. HTRIS functions within a batch mode operating environment and is routinely used by field inspectors to simply extract for each time cycle (usually quarterly) an inventory of bridges due for inspection.

Pontis

Pontis is a comprehensive customizable Windows-based computer decision support system that assists state DOTs and other agencies in preserving and improving the nation's bridge network by supporting the entire bridge management cycle. Pontis was developed in 1989 by American Association of State Highway and Transportation Officials (AASHTO) and FHWA as a cradle to grave BMS. By combining cost and condition data of 120 bridge elements, Pontis finds the recommended MR&R actions for each need. The complete bridge inventory and condition history, as well as project development and tracking information on which Pontis bases its recommendations are stored in a highly developed database which is fully compliant with the data collection requirements of NBIS. Pontis is used by VDOT for other bridge management efforts beyond the scope of this research.

At the inspection level, VDOT uses Pontis Version 3.4.4 to input limited NBIS coded condition data, and safety features. Other inputs used by field inspectors include inputs of inspection date, posting capacity, and the year the bridge is painted. Version 3.4.4 doesn't allow input of any multimedia data including digital photographs and sketches. Pontis has recently released a Version 4.2 that allows multimedia images to be placed within the database, although the images must be viewed through an external application.

Structure Inspection Reports (SIR)

NBIS are that each bridge inspection be fully documented with a written report, appropriate field sketches and photographs, including any recommendations for maintenance or repair and, if necessary, scheduling of follow-up in-depth inspections (NBIS 23, 2002). The bridge inspection staff uses a custom report template created using Microsoft (MS) Word as their inspection report generation tool. The SIR includes text, numerical dimensions, quantities, sketches, computer assisted drafting (CAD) and/or hand-drafted sketches, and photographs (digital and/or 35 mm.) Digital images once inserted into the SIR are archived on local servers, floppy disks, or within the inspector's desktop computer. A centralized indexed digital image archive did not exist. Archiving of the SIR's was another identified inconsistency. SIR's were typically archived in native MS Word .doc format on district servers or central office servers.

Current Bridge and Structure Inspection Processes

Field Inspection Information Process Overview

VDOT bridge inspection teams are composed of two people, a team leader and a team member. Most inspection teams operate from one of VDOT's nine District offices. Within these nine districts are forty-two Residencies. Each Residency is responsible for one to four counties. Each team is assigned bridge and structure inspection responsibility within a particular geographical area (county or counties) and self manages their day-to-day inspection schedule within the required inspection cycles and training guidelines.

Overall inspection scheduling is a function of the bridge/structure's condition, type, the previous inspection date, and NBIS requirements. NBIS requires an inspection frequency not exceeding two years except in special and pre-approved circumstances (NBIS 23, 2002). All bridges within Virginia are inspected on a two-year frequency. Culverts in good condition and not meeting NBIS bridge requirements, as a, are inspected on a four-year frequency.

The information mechanisms used by Virginia to meet NBIS reporting requirements exists as a series of reports using various software applications, and internal databases. This system remains less then fully integrated at the field level. Although minor variations in the inspection process exist among the Districts, the work processes are all similar. As expected, each District uses a combination of computerized and paper based methods to accomplish and document inspections. Each District uses similar procedures for initiating and conducting inspections, and for compiling, distributing, and archiving inspection reports.

The "bridge management databases" themselves are diverse and accessible only through a combination of several different software interfaces. Thus at the inspection level, the three main information interfaces that function independently but are used collectively to manage and record the state's bridge inspections are:

1. HTRIS a non-windows-based operating system (OS) asset inventory database;
2. Pontis, a windows-based BMS software application used for coded condition inputs; and
3. SIR, a windows-based word processing template used for recording commentary, and adding photographs and sketches;

Although there are several redundancies in data storage, each software application can access only certain portions of the entire data structure. The SIR gives the most descriptive, graphical and visual data. Pontis maintains the condition ratings, quantities of element deterioration, and economic data. HTRIS maintains among other items, location, geometric data, current condition states, structure age, traffic counts and special equipment indicator notations.

The fragmentation involved in retrieving electronic inspection information is identified in Table 1 and is partially summarized as follows: 1) Text commentary of current bridge conditions can only be retrieved through the SIR, yet element conditions are accessible only through Pontis; 2) Geometrical data including bridge clearance heights are only accessible through HTRIS. Although similar data fields exists within the Pontis database; Thus acquisition of pre-inspection inventory data is through HTRIS; 3) Graphical data such as scour diagrams, channel profiles and photographic images of a bridge's deterioration are accessible only through the SIR as neither Pontis Version 3.4.4 nor HTRIS have the ability to archive graphic information. 4) Inspection frequencies are available in Pontis and HTRIS, although one inspection team included the next inspection date within their SIR. 5) Condition ratings are typically extracted, when needed, from either HTRIS or Pontis though one team includes condition ratings in their SIR. 6) Maintenance and improvement cost data is usually available only in Pontis although the same entry fields exist within HTRIS. One inspection team duplicates maintenance cost estimates in Pontis and SIR. The inspection staff's use of Pontis was limited to inputting inspection date, coded element and condition data, traffic safety features and date of painting. Repair cost data is then automatically calculated within Pontis using the deterioration quantities previously entered and pre-programmed VDOT construction cost figures.

Table 1 – Locations of Bridge Condition Data

Information Type	HTRIS	Pontis	SIR
• Text commentary			√
• Graphical data (sketches)			√
• Photographs			√
• Geometrical data	√		
• Condition ratings	√	√	
• Inspection frequencies	√	√	
• Element conditions		√	
• Maintenance & improvement cost		√	

Standard VDOT procedures are to allow automatic updating of HTRIS from the coded Pontis data. Some teams manually updated this data. This updating to HTRIS was done on a weekly basis by VDOT personnel other than the inspection team. These automatic updates free the inspection team from dual inputs and potential errors.

Detailed Observations of VDOT Bridge/Structure Inspection Processes

A bridge/structure inspection is a multi-task process that eventuates through four distinct stages or functions. Aspects of each of the four functions may occur during an inspector's daily work processes. The four distinct functional stages of the inspection process and a synopsis of actions

involved at each stage as shown in Table 2 are: 1) inspection management; 2) inspection and condition assessment; 3) reporting; 4) report distribution and archiving. Through analysis Stages 3 and 4 are later combined into a single function called "Reporting."

Table 2 – Current inspection process management stages and actions

Stage	Action
• Inspection Management	• Periodically outputs scheduled inspections from HTRIS server to paper list. • Manually sorts paper list of scheduled inspections, • Marks up paper maps with inspection locations, • Stores reports and maps in folder.
• Inspection and Condition Assessment	• Collects on-site data into pre-configured formats by marking up previous paper reports, • Only the information carried to the site is available for review, • Produces a photographic record of the structure.
• Reporting	• Reports the collected data into HTRIS, Pontis, and SIR electronic formats.
• Distribute and Archive	• Paper copies are made and distributed via mail or hand delivered to end users, • Electronic data is archived in three formats, HTRIS, Pontis, and SIR.

During "Inspection Management," the bridge inspectors collect associated condition data, previous inspection reports, and scheduling information. To complete the "Inspection and Condition Assessment Stage," the inspection team must travel to the bridge site, assess and review the previous bridge report, assess the structure's current conditions, take still photographs, compare existing file data with current conditions, quantify the current conditions and quantify levels of deterioration. They also make any additional notes and sketches to help define current conditions. This stage requires that the inspection team crawl over, under and climb around on the bridge. In many instances there is a stream, as shown in Figure 3, flowing under the bridge. Prior to leaving the site the inspection team mutually concurs and notes the results of the inspection.

During the "Reporting Stage" an inspector will sort through the collected notes, fully document the conditions with any sketches and photographs, prepare a SIR and updates all pertinent information in both HTRIS and Pontis. Figure 1 graphically depicts, in sequential order, the flow of work through the work processes as typically performed by an inspection team. A graphical enlargement for each stage in the inspection process is shown in subsequent figures.

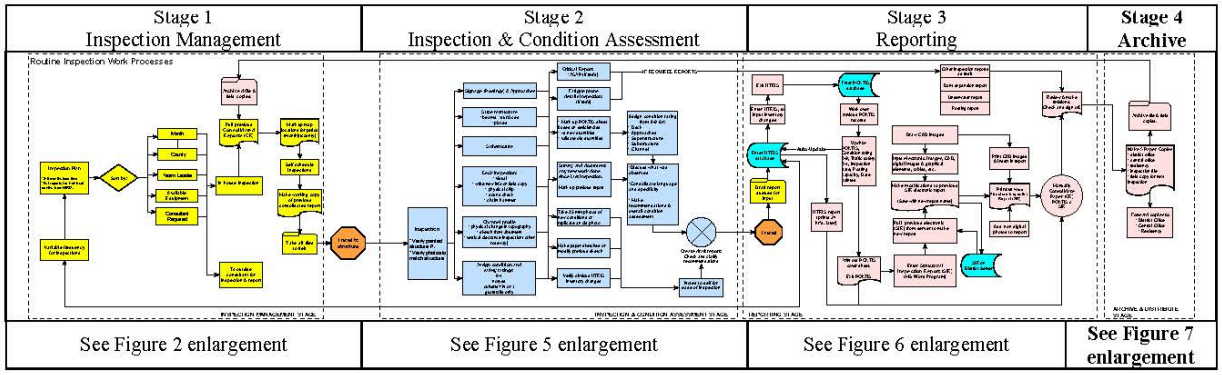


Figure 1 – "Routine Bridge Inspection" Work Processes

Stage 1 - Inspection Management

Figure 2, an enlarged portion of Figure 1, graphically depicts the inspection management stage. The bridge inspection process initiates with the team leader or engineer extracting from the HTRIS database a list of bridges due for inspection during the next 90 to 180 days. This inventory data is downloaded from HTRIS through a query that identifies all bridges and structures located within the team's geographical region that are scheduled and due for inspection during the query period. A direct electronic download from HTRIS to the inspector's desktop is not enabled. Approximately 24 hours after requesting the list of scheduled inspections, a hard copy of the run is produced along with scores of unnecessary paper. The unnecessary paper sheets are a function of the batch mode report process inherent in HTRIS.

The next step in the inspection management process involves the team manually sorting the inventory results according to the following: 1) special equipment needs; 2) month inspection must be completed by; 3) location by county; 4) team leader assignments; and 5) outside consultant requirement. Using the scheduled bridge inventory output the inspection team marks up a county road map showing the exact location of each bridge scheduled for inspection during the queried period.

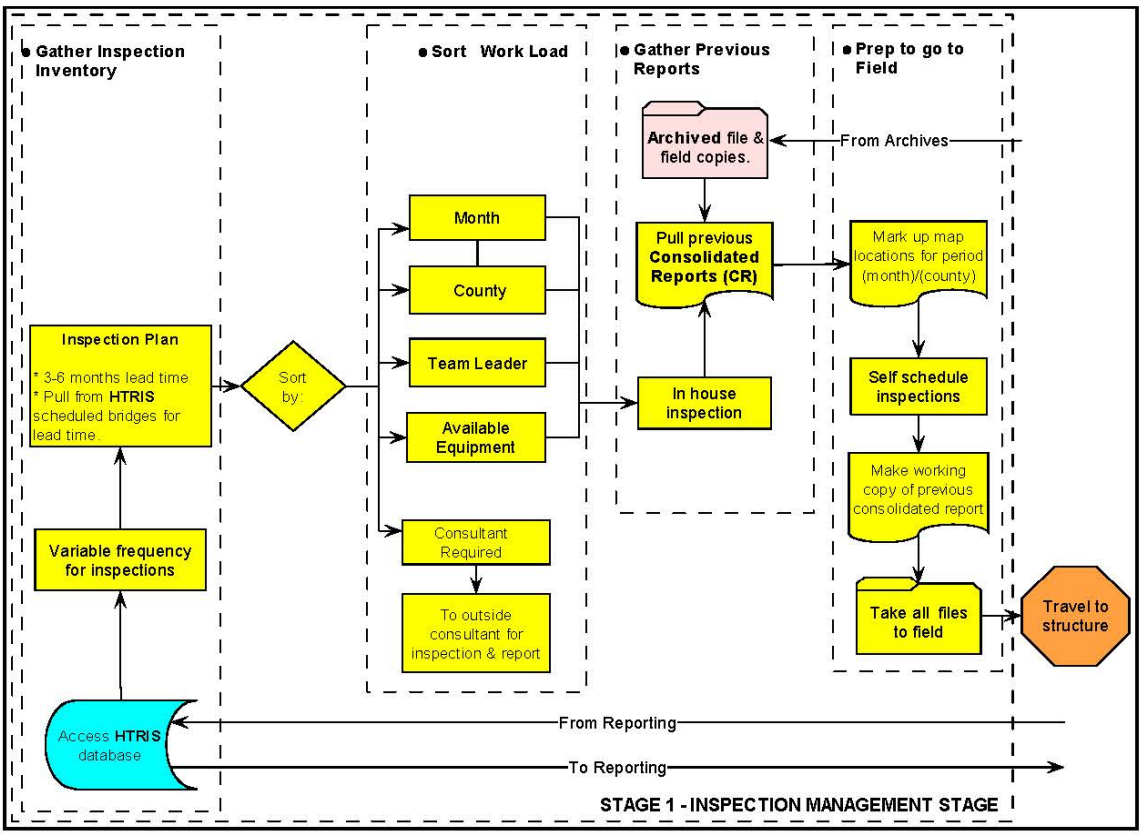


Figure 2 – Stage 1 - Inspection Management Processes

At this point the inspection team accesses the printed archive file and pulls the previous written reports for all the scheduled bridges. Paper folders for each county, are then created; a "bridges due" folder and a "bridges inspected" folder. Working copies of the previous reports are placed in the "bridges due" folder. Once this is set up the inspection team is ready to go inspect bridges.

From the work flow mappings, it is apparent that three archival objects must be extracted from multiple information sources to complete the inspection management stage. These objects and information sources are addressed in Table 3.

Table 3 - Inspection Management Objects Needs and Archival Sources

Archival Object	Information Source
Paper output of scheduled bridge inspections	HTRIS database, electronic run, manually sorted
Previous paper report	Archived report files are manually printed
Paper county maps	Maps file with manual location markups on the maps

Stage 2 - Inspection and Condition Assessment

Many bridges are located on rural roads with overgrown vegetation, low clearance, and spanning a creek or stream. Figures 3 and 4 below show the typical environmental conditions that inspectors must work in. In addition to wearing hip waders, safety vest, and personal protection equipment the inspector must carry other equipment to assist in the inspection. A clipboard with the previous inspection report for note taking, as shown in Figure 4, is carried throughout the inspection. Each team also carries many other items that are essential for conducting a routine bridge inspection. Among these items are:

- visual aid tools including a camera, binoculars, flashlight, magnifying glass, mirror, etc.,
- basic measuring tools including tape measure, punch, plumb bob, etc.,
- cleaning and inspection tools including brushes, scrapers, screwdrivers, pocket knife, ice pick, pecking hammer, probing rod, etc.

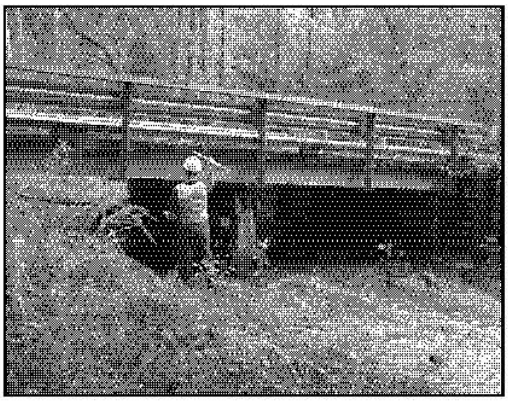


Figure 3 – Super-structure inspection

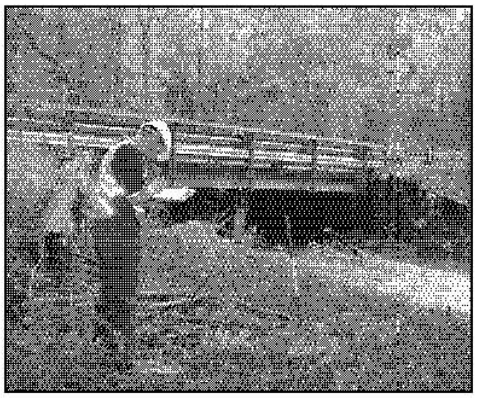


Figure 4 - Making paper field notes

Most but not all of the above tools are carried throughout the inspection processes by one or both team members. The two-person team works in tandem with one person usually taking the notes

and the other member verbally instructing the note taker on conditions being observed and/or measured.

The actual inspection and condition assessment occurs in a sequence of five basic tasks. These five basic tasks that an inspection team will perform during a routine inspection are:

1. confirm that the bridge matches the scheduled inspection and the previous inspection report;
2. a systematic inspection, using visual and physical methods, including site photographs;
3. documenting, on the previous report, the currently observed conditions;
4. assign and confirm condition ratings and element condition quantities;
5. confirm and concur that the inspection is complete.

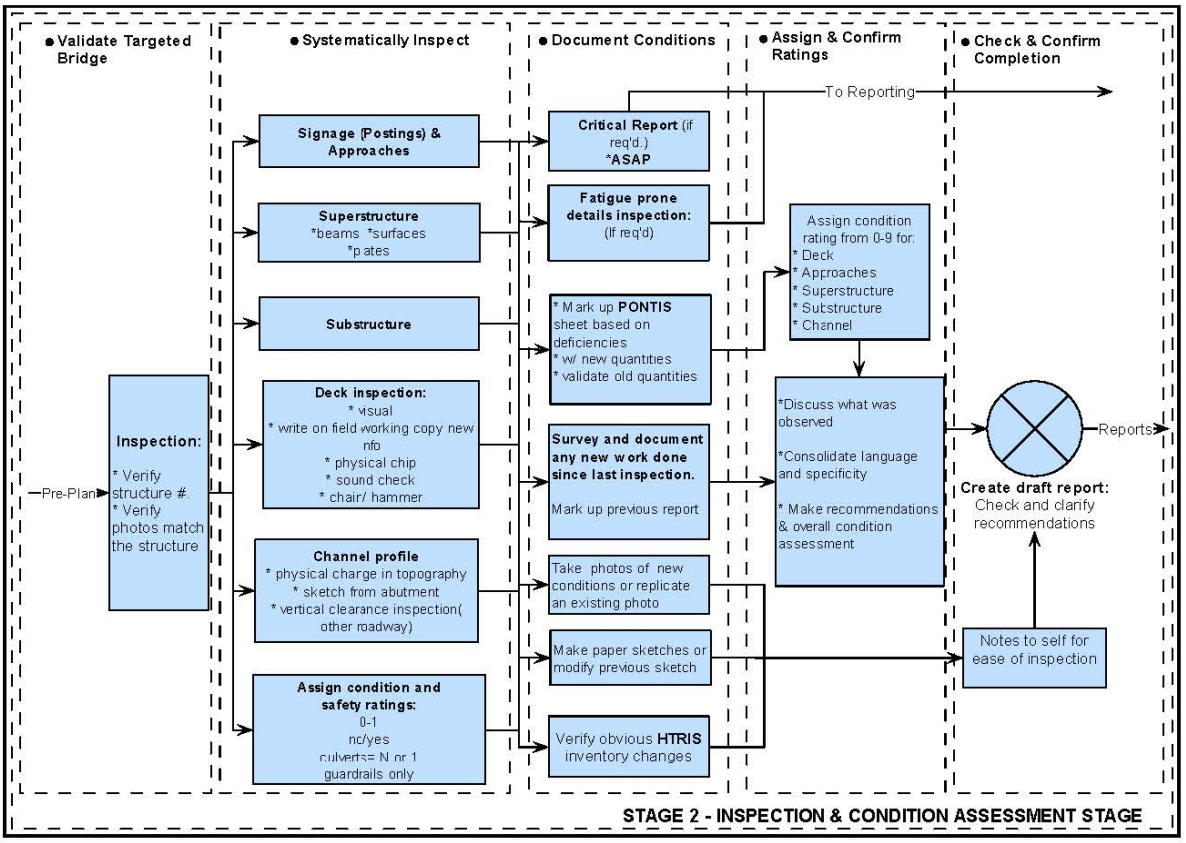


Figure 5 – Stage 2 - Inspection and Condition Assessment Processes

Figure 5 graphically depicts the Inspection and Condition Assessment Stage and the five sequenced activities each team follows in completing a routine inspection. Upon arriving at the site, the inspection team verifies that the bridge matches the scheduled and that the previous report also matches the scheduled bridge. An inspection team uses one or more of four verification methods,

1. the structure number stenciled on each bridge matches the structure number on the previous report;
2. the photographs in the previous report match the structure;
3. distances from adjacent route intersections are verify;
4. by the use of geographical positioning system (GPS) coordinates.

Both geographical coordinates and bridge numbers are included within HTRIS. During the field observations only methods one and two above were used. This was attributed by the inspector to their familiarity with the particular bridges being inspected. There was no GPS verification done for any of the six inspections witnessed. The inspectors stated that GPS equipment and coordinates are typically needed when doing a culvert inspection.

The actual inspection is performed combining visual and physical inspection techniques. All new work completed since the last inspection is observed and reported. Photographs of the bridge approaches are immediately taken. Throughout the inspection additional photographs are taken and new sketches are drawn or existing sketches modified to match the conditions. The physical inspection process (semi-destructive in nature) involves probing, gouging, tapping, pecking, scraping, etc. to determine the extent of decay, corrosion, and deterioration of each structural element. Each element, beam, cap, pier, plate, wearing surface, etc. is individually inspected and the conditions noted.

The inspection proceeds aided by the previous inspection report and predefined categories identified in Table 4. The SIR is structured with the same categories allowing a concise blueprint to "checklist" a complete and thorough inspection.

Table 4 – NBIS Inspection Categories

Types of inspection	General Points of Inspection
Approaches	Check for vertical alignment and slopes
Decks	Check for wearing surfaces
Superstructure	Check beams, surfaces, and plates
Sub Structure	Check pier caps, columns, undermining and slopes
Signage	Check for required signs, postings
Channels	Check for debris, flooding, changes in the channel

As the inspection progresses, each element is quantified and either physically measured or "eyeball measured" to ascertain quantities and conditions of deterioration for assigning NIBS ratings. The deck, superstructure, substructure, and channel, all receive condition ratings on a 0-9 scale. These ratings and element condition states are later reported in Pontis. A channel profile must be determined and documented. This includes checking for any changes in topography, measuring vertical clearance, channel depths and producing a field sketch of the profile and clearances.

All teams documented their inspection results by marking up the previous inspection report (Figure 4). The team then makes note of any recommendations for maintenance and repair and assigns an overall assessment of the structure. If observed deterioration indicates that the load carrying capacity of the bridge is affected the inspector will perform several quick calculations and make a judgment call regarding recommendations to downgraded the bridge capacity. If it is

suspected that the load carrying capacity might go down, an engineer will make additional computations and then make a final decision on the structure's load carrying capacity. Any inspection that deems a structure to be in a critical state requires immediate completion of a "critical report." Before leaving the site the inspection team will check, clarify and mutually agree upon all ratings, maintenance and repair recommendations and note any HTRIS inventory changes.

Stage 3 and 4 - Reporting, Distribution and Archiving

Although reporting, distribution and archiving are considered distinct tasks they are functionally combined in this summation. At the inspector's office, the draft reports are completed upon return or more typically, queued for later completion. Any digital images are uploaded from the camera to the inspector's desktop computer for later inclusion when the report is prepared. Photographic film, if used, would be taken to a film processing facility for development and later pickup.

The report compilation sequence varies from team to team but all teams complete the same tasks as noted below,

1. prepare a SIR;
2. input inventory changes into HTRIS;
3. input condition data into Pontis;
4. prepares a Consolidated Structure Inspection Report (CR) in a paper format, combining the "front (summary) sheet" of Pontis and the complete SIR.

Figure 6 below identifies HTRIS as the first reporting element, followed by Pontis and then the SIR. The sequence may vary from inspection team to inspection team, e.g. a team may finalized the CR and then update HTRIS. All teams will make inputs to HTRIS, Pontis, and SIR, and output for official transmission and archival purposes are paper copies of the Pontis summary sheet and the SIR that forms a CR.

HTRIS Reporting

HTRIS is typically updated with changed and/or omitted bridge data added to the existing fields. No new data fields are created by the inspection team. Typical entries into HTRIS are done both manually by the inspector and automatically by weekly uploads from Pontis. This automatically uploaded data from Pontis to HTRIS consists of condition ratings on a 0-9 scale; traffic safety features using a 0-1 input; inspection date; posting capacities, and date painted. Any inventory changes, notably vertical height clearances and/or other geometric data are manually entered into HTRIS by the inspector. The HTRIS database was automatically updated from a Pontis upload done weekly by personnel other than the inspection team. At least one team was observed making manual updates to portions of the HTRIS database that were to be automatically updated. As a matter of standard procedures, during the time between weekly uploads from Pontis to HTRIS, two different sets of condition data exists, one in HTRIS and the other in Pontis. Only one team stated they added maintenance cost to the HTRIS database, and then only if cost were applicable due to the observed bridge conditions. There was no verification if cost additions

were a standard procedure, for the Residency, District, or simply the team. Standard operating procedure for the Bridge/Structure Division is to have cost data automatically generated by Pontis from inspector entered quantities of element deterioration.

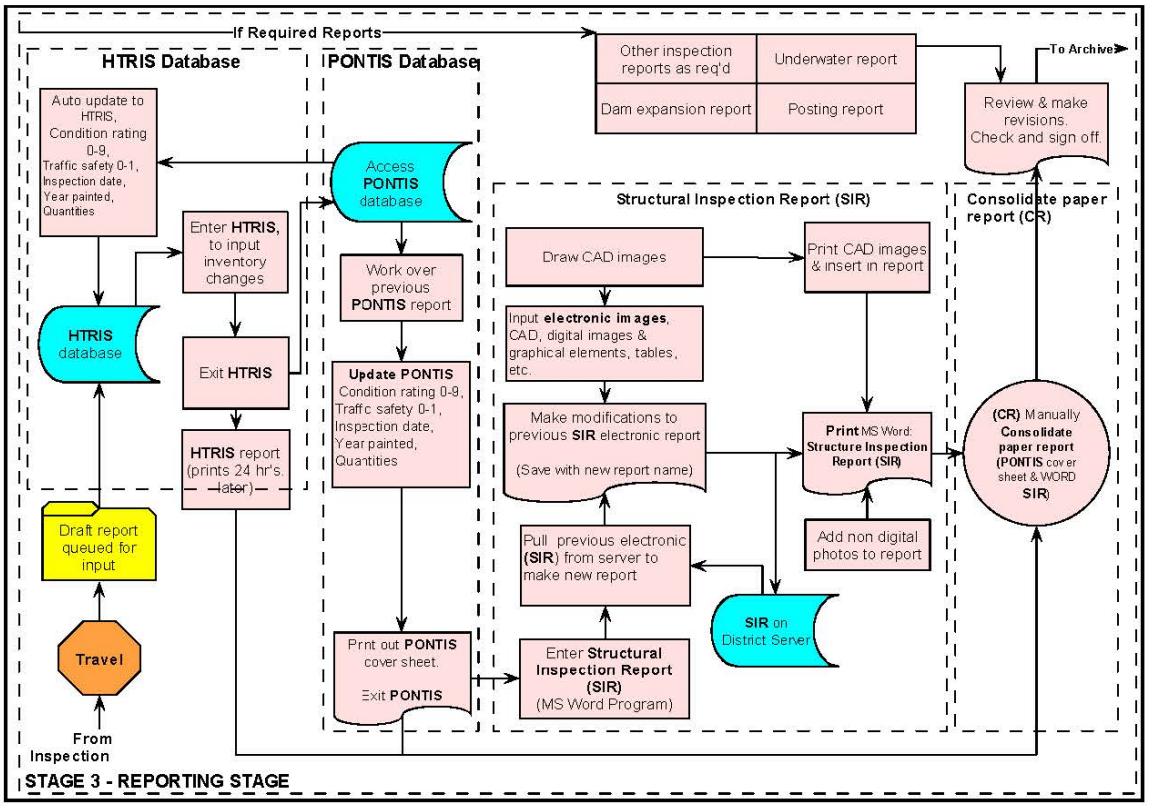


Figure 6 – Stage 3 - Reporting Processes

Pontis Reporting

All teams updated Pontis in a similar manner. Much as when updating HTRIS, the inspection enters limited data into Pontis. There was some observed redundancy in updates. The inspection team enters various element quantities and their condition, i.e., their state of deterioration, and NBIS ratings on the 0-9 scale for deck, superstructure, substructure, and channel. The inputs are limited to NBIS based coding, or involve deterioration quantities. Upon completion of data entry a "summary" sheet or "cover sheet" as the inspectors call it, is printed out and attached to the SIR forming the CR.

Structure Inspection Report (SIR) Reporting

The final reporting effort involves completing a SIR. The SIR is a text and graphics based report that states provide a verbal commentary describing the structure's condition. The report is produced using a standard word processing template based on the same categories described in Table 4. Each inspection team modifies the template at their discretion to simplify and eliminate unused fields. The "fields" are text based and do not contain any database functionality.

Unless a first inspection is taking place, a new SIR is created over an existing SIR. Modifications are made to the previous SIR based on the field mark-ups. Sketches and drawings are electronically created and inserted, digital photographs, if available, are also inserted. If 35mm photographs are used, the inspector must first print the paper report, and then paste the photographs into the report.

After all modifications, sketches and photographs are inserted, the report is ready for a consolidation. Consolidating consist of combining the Pontis summary ("cover") sheet with the SIR to form the CR. It is this CR that has all the necessary information on bridge conditions in a single report. The final report (CR) is complete and ready for sign-off by the team leader, and engineer. After sign-off the report is the given to secretarial staff for copying, distribution and archiving.

Archive and Distribute

After the CR is reviewed and signed-off its distribution is handled slightly different by each District. Figure 7 depicts the distribution and archival process. Between three and five copies of the CR are prepared and distributed. In all instances copies are officially forwarded to Central Office, District, and Residency, any remaining copies and the original are placed in the archive folder. An electronic copy of the SIR is retained on servers in native MS Word .doc format. The choice of server location varies by District, with some SIR's residing on Residency servers, others on District servers. Internal document protection was not provided.

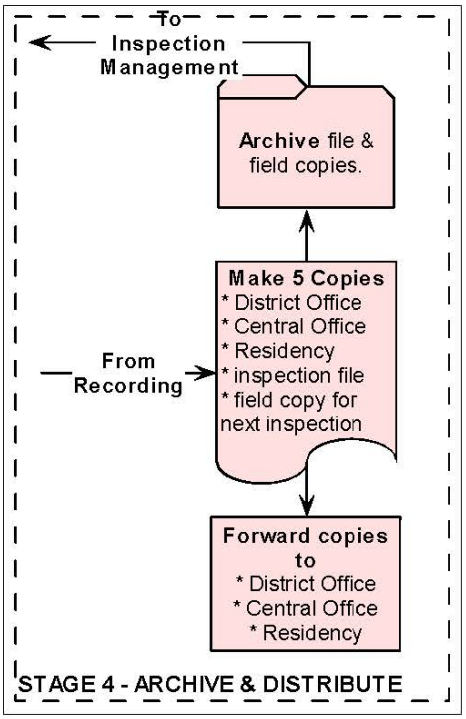


Figure 7 - Stage 4 - Archive & Distribute

Information Automation in Bridge/Structure Inspection through Mobile Computing

Mobile Computers

There are three classes of mobile computers making their presence known in the inspection field; 1) handheld computers, 2) wearable computers, and 3) pen-based tablet computers. These three classes of mobile computers are all battery powered, lightweight tools that can be carried, hard cased, holstered, or strapped to the inspector's wrist in support of field data collection. The tablets and wearable computers are full blown Windows computers, miniaturized to allow them to strap or hang on the body. Navigation and data entry inputs vary among tapping with a stylus, virtual and physical keyboard typing, hand written character recognition, and/or speech inputs.

Personal Digital Assistants (PDA), Palm and PPC's are miniature-sized computers that combine the benefits of handheld pen-based input, long battery life and low cost

with graphical user interface. Because these computers have high storage capacity and high quality writing recognition, they are well suited for form-based electronic entry of field data, much as current bridge inspections are done. Nathwani's experiments indicate that typically, several field inspections can be performed before the collected information needs to be uploaded to a desktop, laptop, or synchronized with an online server. Software to make these transfers, in addition to Geographical Information System (GIS) and GPS application interfaces are available (Nathwani, et al, 1995).

Palm computers, PPC's, and PDA's, differ mainly in operating system, range of applications, and computing power. Most PDA's use a Palm OS and have low computing power. Their primary purpose is to act as a contacts and appointment manager. PPC's are based on the Windows OS desktop metaphors (Windows CE/Mobile 2003) and consequently offer many of the same applications developed for desktop computers. A typical PPC is delivered with Pocket Word, and Pocket Excel, and a digital image viewer. In fact, the standard SIR template was able to be downloaded to a PPC and edited in the field. Pocket Adobe Reader for reading .pdf files is also available as a free download. Palm computers have similar capabilities although conversion software is necessary to use MS Word and MS Excel.

Visual CE is a Windows CE programming language that also allows for easy creation and development of data entry forms linked to database applications including Oracle. There are also several other PPC database programs that allow synchronization with server based databases, including MS Access and Oracle. As a result, standardized data forms are easily replicated for PPC's and data entry can be input in an electronic manner similar to manual bridge inspections. Because PPC's have more memory than Palm's and PDA's, they can store more field inspections, on-site field sketches and even record signatures (Elzarka et al, 1999). Since Elzarka's research, both Palm and PPC's are able to have digital cameras, large size memory cards, GPS devices, barcode and radio frequency identification tag (RFID) scanners, directly attached for improved data collection.

In addition to PDA's and PPC's, wearable computers offering hands-free and/or near hands-free technologies have been developed and explored in bridge inspection environments (Sunkpho and Garrett, et. al, 1998). Among the major manufactures and developers of these devices and applications are Xybernaut, and VoCarta. Xybernaut, a Virginia based company, is a leader in wearable computers that utilizes head mounted displays and VoCarta speech recognition software to navigate and input data. VoCarta has developed the capabilities of converting speech-to-text, and also of entering spoken information directly into relational and spatial databases including GPS coordinates, digital photos, audio files, laser measurements and other relative information. VDOT is trial testing this technology in a project called Inventory and Condition Assessment System (ICAS) with Parsons Brinkerhoff as part of their Integrated Maintenance Management Program (IMMP) (Irving & Anderson, 1999).

Speech Recognition

Speech recognition is a promising technology for assisting in the development of hands-free data collection and has an excellent capability to assist in bridge inspections. This application is well developed in the medical examination and transcription field and also holds promise to migrate

to other fields including inspection processes. TalkNotes developed by Roanoke, VA based ProVox Technology allows healthcare providers to use PPC computers to dictate patient notes during or following an examination.

Examination notes or other dictation is done directly into a PPC and stored on a "compact flash" media storage card. This card is inserted into a card reader attached to a desktop PC and the files are downloaded, automatically turned to text, and inserted with other note information into the user's written forms or templates. The software is developed with specific medical vocabularies and terminology. ProVox states 90-98% transcription accuracy after trained the software in specific voice recognition. The software also includes an "Active Notes" feature that allows previous patient medical history to populate current histories (www.provox.com, 2003). Speech recognition technology combined with PPC's holds future promise in providing bridge inspectors with an innovative system for accurate and rapid field data and asset information collection.

Radio Frequency Identification Tag (RFID) Systems

A prototype on-site inspection support system has been developed by several Japanese researchers that offer several possibilities in alternative bridge inspections techniques. This system as developed by the researchers consists of a RFID tag system, a PPC connected to the Internet, a voice input/output system, and a digital camera. A field inspector carries a PPC, a cellular phone, and a digital camera. The PPC also has an RFID tag "reader-writer." RFID tags are computer memory chips sealed in a stainless steel "button" affixed or attached to an object such as a bridge. The data storage capability of these "buttons" is 64KB of read/write memory, in effect 65,000 characters. According to one source there are over 75 million of these RFID tag buttons in use (Maxim/Dallas Semiconductor Corp., 2002).

A microphone/speaker headset is attached so that the inspector can record and reproduce his or her voice. The system is also equipped with a PC wireless Local Area Network (LAN) card so that inspectors can have access to a data server via the Internet. The Japanese research team investigated cost, efficiency, availability, advantages and disadvantages of information access methods, and concluded that a "hybrid method," combining a central server, the RFID tags (with up to 3MB of memory) at the site, and a PPC downloaded with certain data as the most suitable for an inspector's mobile tool. In the hybrid method, RFID tags contain basic data about the facility or member, such as the ID, main feature or specification, inspection procedures, latest measured data, latest inspection notes, etc. The PPC contains measurement data, digital photographs, digital sounds, information about inspection routes, etc. within available storage limitations. The remote office server contains all the archived data, documents and drawing files not carried to the site in the PPC (Yabuki, et al, 2002). Thus, the inspector can store or receive data, a digital image, and other data to/from a PPC, an RFID tag at the site, or central office server in order to obtain needed technical data.

Experimental Automated Bridge Data Collection Methods

Fanous et al (1996) working with the Iowa DOT developed two automated data collection methods for conducting bridge inspections in the field: the Automated Data Collection (ADC)

program and the Pontis Data File Creation (PDFC) program. Both are software applications written for handheld pen-based computers for data collection in support of the Pontis BMS. Onscreen help menus are provided to help the operator with the use of the software.

In the ADC program, the user is required to follow the steps listed in the main menu. These steps are divided into two parts. Part 1 deals with defining bridge information (e.g., FHWA number) and the bridge elements to be inspected. In Part 2, bridge inspection data are collected in the field to rate the condition of a bridge element using a standard condition states. The ADC program provides the user with this information and also allows the user to prepare inspection reports in the format used by the DOT.

The PDFC program was developed to prepare ADC data files as input files for the Pontis BMS. Like ADC, the PDFC has on-line help menus that provide descriptions for each condition state of defined bridge elements requiring inspection. The program was able to combine inspection data from different bridges into one informational file for use by the Pontis optimization routines when applying different maintenance strategies. This software was trial tested with the Iowa DOT and numerous changes made to improve its focus as a field data collection tool and a translator to prepare field data for transfer into Pontis.

In 1995, Trilon, Inc. developed its "Inspection on Hand" (IOH) a commercial bridge inspection program. Like ADC and PDFC, IOH is designed to support a Pontis BMS using a PPC. IOH simplifies the data gathering process by guiding bridge inspectors through Pontis inspections with pop up menu screens (www.trilon.com/trilon, 2002). Because all of the information required for Pontis inspections is contained in the IOH software, IOH is offered as ideal for states using or converting to Pontis BMS. Much like the PDFC, IOH uses a translator file called the "Pontificator" to download native Pontis files to the mobile device in IOH format. Upon completion of data collection, the PPC is returned to the office and inspection data uploaded to the Pontis server, automating updating the Pontis data fields.

The software allows inspectors to generate complete Pontis formatted inspection reports, including non-coding items such as inspection commentary or field notes and then transfer the files to the Pontis BMS. This product's user manual states that the IOH software is designed to work with Pontis 3.4 and also states that since the inspection process is paperless, the need for filing and managing paper forms from past inspections is eliminated (Trilon, Inc., 1999). As is the case with Pontis 3.4.4, multimedia objects such as digital images and CAD drawings cannot be linked or embedded. Trilon is continuing development of their software to be compatible with Pontis 4.2.

Innovative Inspection Data Collection Applications

Several automated bridge inspection data collection systems have found application through limited field research, although one of the systems has been commercialized and another system from France is being adopted domestically. These applications are the Automated Bridge Inspection System (ABIS) researched in conjunction with the South Carolina DOT (SCDOT). The Integrated Bridge Inspection Information System (IBIIS) developed in conjunction with Massachusetts Highway Department and with the Rhode Island DOT (RIDOT), and converted

by Trilon, Inc. to commercial purposes. Recently another commercial product developed in France is ScanPrint by the Advitam Group. This application is being distributed domestically through a Columbia, MD subsidiary and being used to support portions of the Michigan DOT BMS.

ABIS was developed by Clemson University and the SCDOT using the Padbase Software Development Kit. For each bridge, more than 200 fields are stored in the database (Elzarka and Bell, 1997). Padbase form-design capabilities have allowed the replication of the paper forms currently used by the SCDOT. Prior to a new bridge inspection, the old inspection data is transferred to the handheld so that the inspector has full on-site access to previously collected data. When an ABIS form is displayed on the tablet, the inspector can update the database by simply crossing out old values and entering new with the pen. ABIS recognizes the printed handwriting. The inspector can also use ABIS to perform database queries; access referenced material, and navigates between forms using buttons. Another valuable capability of ABIS is its ability to draw and store field sketches (Elzarka et al, 1999). SCDOT has implemented ABIS since 1995.

The IBIIS was developed jointly by Trilon and Iffland Kavanaugh Waterbury to serve as a computerized database for the information management needs of bridge engineers. IBIIS stores and automatically organizes all information centrally, allowing instant and simultaneous access by everyone connected to IBIIS (www.trilon.com/trilon, 2002). An IBIIS on-site software add-on allows inspectors to bring data from the IBIIS central repository to the bridge site for data review and update.

IBIIS was designed to manage all the information associated with bridges including inspection reports, load rating reports, correspondence, inventory sheets, color photographs, plans, videos, and electronic files (CAD, Word Processing, Spreadsheets, etc.). The system features electronic data capture via still and full motion video cameras, digital cameras, high-speed black and white scanners, color scanners and large format scanners. The archived information can be printed or carried into the field or viewed electronically using the IBIIS on-site detached viewing software.

IBIIS is used extensively by the Commonwealth of Massachusetts Highway Department and RIDOT. By mid-1995, RIDOT had over 70% of all bridge information on-line on IBIIS, with 100% on-line expected by the end of that year (Nathwani and Shroff, 1995). The software is also being expanded for use with other structures such as tunnels, buildings and signs. Trilon, Inc. has refined and commercialized the product and now markets it for assistance in field data collection, and reporting within the Pontis BMS framework. It is now used by 12 state and federal transportation agencies, including the FHWA (www.trilon.com/trilon/, 2002).

The French product ScanPrint, by Advitam Group, is intended as a BMS but does not incorporate an interface with Pontis. ScanPrint is a sophisticated program that integrates data collection, structural analysis, and asset management within its suite of modules. This product is being used in the US extensively by bridge inspection consultant, Parson Transportation Group for data collection and bridge management (Sawyer, 2002). ScanPrint is operated from pen-based tablet computers hung from the body, thus allowing some hands-free movements. Figure 8 shows an example of electronic note-taking being done on a tablet PC using ScanPrint.

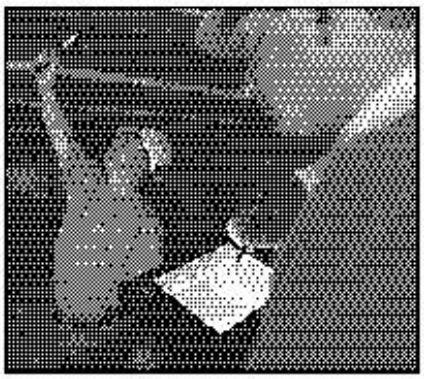


Figure 8 – Making electronic field notes (Finley-McNary, 2003)

Its management module enables the user to define asset inventory with the normal alphanumerical coding, assign geometrical data, input CAD drawings, and provide element definitions, digital photographs, and "smart facets." "Smart facets" are intelligent attributes prescribed to materials, environmental conditions, structural components and structural behavior. These all combine to assist in simulating bridge deterioration over time and by applying various maintenance and use strategies (www.advitam-group.com, 2002).

The basic features incorporated into the ScanPrint data collection module are the ability to have instant access to various bridge inspection manuals, to view drawings of the structure being inspected, to access and view past inspection reports, and has an inspection check-list for each structural component of a particular bridge. If element deterioration is detected the inspector can draw the shape of the deterioration directly onto the computer screen. The inspector can then reference the deterioration to more than 200 deterioration types classified by families of deterioration. The software is also configurable to link marked up digital images with associated text commentary to CAD files (Le Diouron and Stubler, 2002). All information is displayable on single screen at the same time (www.advitam-group.com/, Mackinaw Bridge, 2003).

A final mobile field application worthy of notation due to its use in "water, farm fields, woods, bushes, and other inconvenient places…" is DTE Energy's adoption of IPAQ PPC's to carry out power pole inspections and gas leak surveys. Daniel Fletcher, an analyst with DTE notes that although users were skeptical of the small screen size and screen reflectivity, "they work fine," around water, in the woods, and in the bushes. In conclusion, Fletcher notes a labor cost reduction, faster turn around on damaged poles, and good user acceptance, noting that no units were "lost" and only two repairs were required of the 12 units put into service during the 12 month evaluation period. He attributes this to assigning the PPC's to inspectors just as if they owned the tool (Fletcher and Marlin, 2003).

ANALYSIS OF INSPECTION WORK PROCESSES

VDOT oversees bridge inspections through a Central Office of the Structure and Bridge Division. Actual bridge inspections are conducted by inspectors that are located in several geographically defined Districts. In general the inspection processes are similar. The data collection and reporting system is paper based, and archived in three separate electronic applications ands formats and a single paper format. Data collection is done in the field by marking up previous paper reports with "new" data. Later inspectors manually input "new" data into electronic applications and print out a paper archival report, the CR.

The effectiveness of data collection is constrained by the current methods of data capture and then further constrained by processing multiple documents, i.e., using existing reports to create

draft reports, and then transcribing the draft reports into "new" HTRIS and Pontis data sets. Contained within the new reports are multimedia objects, particularly photographs and drawings that are either manually added to the new report or electronically inserted after being created, saved and stored separately. As a result there are between five to six generations of data compilation and report creation necessary to create a single final inspection report. According to Leung (1996), document management poses a perplexing task to transportation agencies across the country. Toward resolving this problem many DOTs have instituted efforts to develop automated methods to assist in solving the data collection and document reporting problem. These automated methods to document, store, and retrieve offer great promise to improving the inspection processes. Table 5 restates the basic inspection stages identified in Table 2 into functional areas with its electronically assisted actions, while Figure 13 depicts the internal function/action dependencies within a mobile computing inspection process. Only through a concept of total process integration can transformation reach its greatest potential.

Table 5 – Alternative inspection process management functions and actions

Function	Action
Inspection Management	• Prepare and schedule for inspection, • Transfer data from server to mobile inspection device.
Inspection	• Collect data on-site with mobile inspection devices, • Collect data on-site into pre-configured formats, • Enable on-site mobile access to remote data, • Perform photographic record inspection of structure.
Reporting	• Report collected data in NBIS, and VDOT formats, • Automated uploading of data into standard report formats, • Allow "push/'pull" report distribution, • Store archive data on server in a query capable format.

An analysis of the bridge inspection process proceeds through three distinct functional areas as shown in Table 5: 1) inspection management; 2) inspection; and 3) reporting. In general the Inspection Management process, Figure 2, requires the inspector to download an inventory of bridges to inspect, sort and map locations and then gather tools and previous data necessary for the inspections. The Inspection process, shown in Figure 5, physically occurs at the site and involves significant physical activity with a wide range of body motions (Figures 3 and 4). Reporting, distribution and archiving are shown in Figures 6 and 7 and is done by the inspector, in the office, and follows NBIS guidelines for reporting and state guidelines for distribution. Currently, the reporting function involves accessing among three to five software applications in order to complete a report. The computer applications used to complete a single inspection report are Pontis, HTRIS, a word processing program, a digital image program, and a CAD program.

Upon completion of data entry, the reports are output to paper and physically combined to form the final paper report. As an archive, the final report, the CR, never exists as a single electronic document. The inspection data resides electronically separated in at least three locations, Pontis, HTRIS, and SIR. This is due to the fact that the Pontis "cover" is neither exported nor captured into the SIR, nor is the SIR imported to nor captured within Pontis. Thus the final report is a paper compilation from parts of the various software applications assembled by the inspector,

electro-statically copied, and then mailed for departmental use and archiving at multiple locations within the VDOT organization.

Analyzing the work processes yielded insights that all three inspection process functions are inefficient and can be enhanced by using mobile computing devices to integrate and assist the different inspection functions. Briefly the areas of opportunity for improvement and enhancement are:

- Stage 1 – Inspection Management: Previous report access and bridge inventory data gathering during this stage are two areas that data filtering and exchange can assist inspection teams.
- Stage 2 –Inspection and Condition Assessment: Field data collection using mobile computers and attached digital devices with automated information transfer capabilities offers another opportunity.
- Stage 3 – Reporting: Multiple reporting programs create redundant data entry and fractured data integration. Mobile computers with attached digital devices and synchronizing capabilities can integrate and improve data reporting, transfer, storage and access, across the entire process.

Stage 1 - Inspection Management Process Analysis

Inspection management involves pre-planning the inspections over a 90-day period. Currently bridge inspectors use hard copies of previous reports to verify old data and mark-up new data in the field. While this process is convenient for the inspector in terms of initial data entry, one weakness to this method is the inefficiency in gathering such widely diffused data. The ability to extract data precisely and quickly is one area of process transformation that can benefit from the integration of mobile computing devices. During inspection management only one electronic action is taken while three manually actions are applied (see Table 3). Transforming the other three processes to automated functions can simplify the process and enhance productivity.

Electronic access to HTRIS allows the inspector to locally run a query, using a date range filter, through the database for batch extraction of all bridges due for inspection and their associated inventory sheets. Paper output is delivered 24 hours later and the results are manually sorted based on other parameters, such as county, month, equipment needs, and consultant filters. The sorted data is then used to manually mark paper maps for the locations and proximity of bridges.

One method for improvement during this stage is to develop a query and method that filters and sorts the data electronically and locates the bridges on digital maps. Figure 9 shows an alternative work process for Inspection Management. This alternative uses query filtering and sorting through a single database that outputs scheduling, inventory data, condition and element ratings, electronic maps and SIR type commentary. The output results in a single unified electronic file that is internally hyperlinked and contains all necessary inspection information currently extracted from HTRIS, Pontis and SIR sources. The information can then be downloaded to a mobile computer and/or printed to paper.

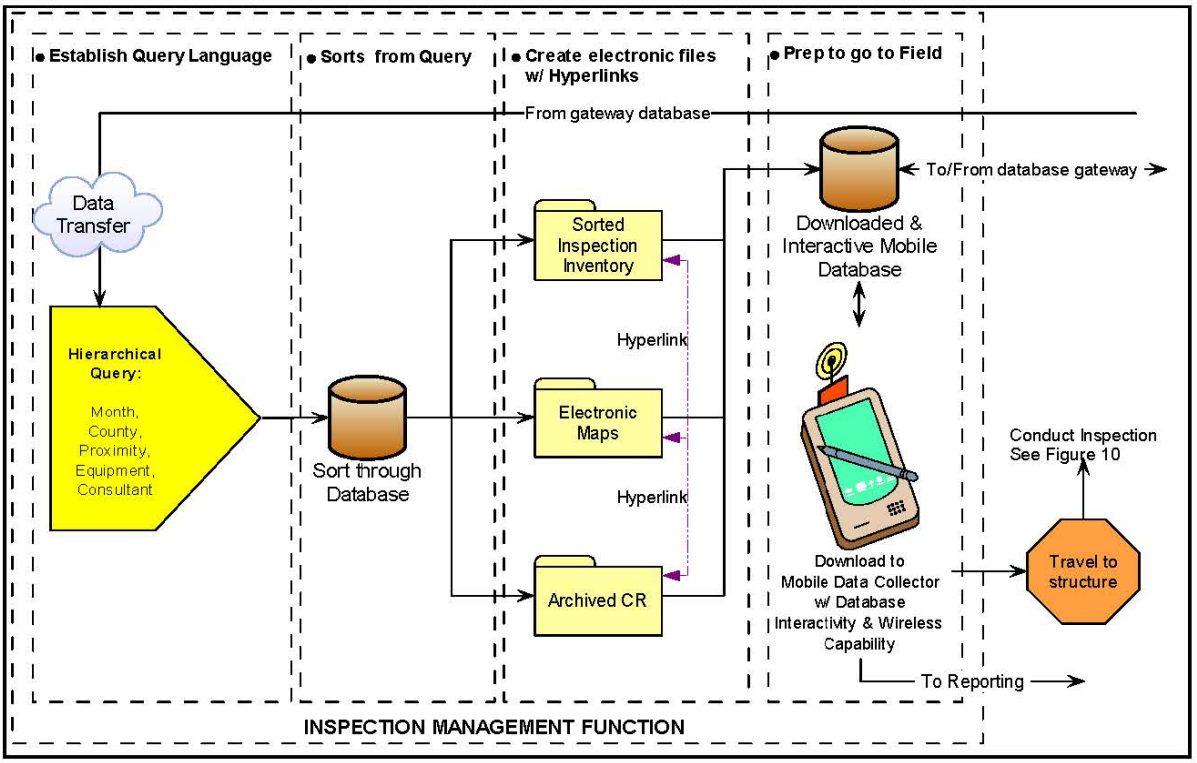


Figure 9 - Alternative Stage 1 - Inspection Management Function

One particular action that transitions between Inspection Management and Inspection is bridge verification. The current method of matching bridge to report is effective when the stenciled numbers remain visible and the intersections and vegetation remains stable. However, additional techniques such as barcodes, RFID tags, and GPS can be employed for automatically locating and verifying bridge coordinates. By scanning a barcode, using GPS, or accessing an RFID tag not only can the bridge's identity be field verified, but other relevant information can be accessed, including structural data, inventory data, and condition ratings. This opportunity also embraces emergency inspections when data access is critical and time is short allowing immediate onsite access to critical bridge information.

Stage 2 - Inspection Process Analysis

To support the Inspection Stage with mobile computing involves: 1) developing a tool that allows error free field identification of specific bridges (GPS, RFID, barcode), 2) enabling a systematic inspection process (electronically guided and edited field forms), 3) provides for a hands free operation (wearable computer), 4) can incorporate multimedia inputs (digital camera), and 5) has database interactivity (compatible input/output databases). Figure 10 depicts an alternative process that incorporates flexibility and mobile computing into the Inspection function. The use of a mobile computer with the ability to input data electronically by talking, writing, typing, picking, taking digital photographs, and electronically sketching is of paramount importance in developing a flexible and integrated digital assistant for field inspectors.

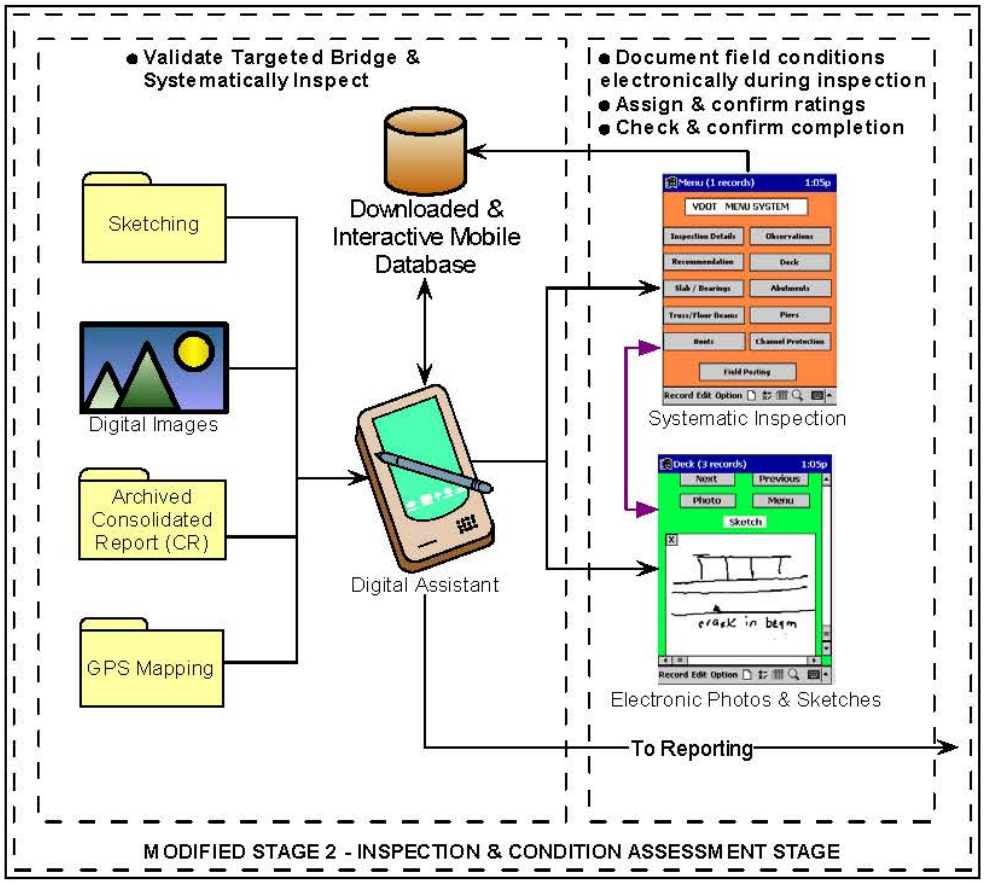


Figure 10 - Alternative Stage 2 - Inspection Function

The Inspection function is characterized by field data collection through a physical inspection of bridges and structures that are spanning waterways, and other roads. Evident from the observations are the requirements for dexterity, agility, and the extensive use of an inspector's hands to climb about, and manipulate various tools during the inspection. Therefore in developing processes that encompass mobile computing tools, consideration should be given to a tool that frees the inspector's hands during both inspections and inputs. The most desirous tool is one that assists or leads the inspector through a systematic inspection either through voice inputs or assisted by "smart tag" or "macro" inputs.

"Smart tags" are simply automated actions that once initiated complete the action with minimal keystrokes. An example of this approach is the establishment of an "inspection vocabulary" that addresses common deterioration observations and/or condition assessments and automates data collection using speech, or with minimal keystrokes. These inputs can be single words, paragraphs, or quantification statements derived from common field observations and standard inspection vocabulary. This leads optimally to a wearable computer with speech activated inputs for data collecting within standardized formats.

The need for inclusion of multimedia objects including previous reports, new and existing photographs, drawings, sketches, and digital signatures is apparent from the analysis. One process that immediately lends itself to digital improvement is the use of digital image capture during inspection. All inspection teams should be issued a digital camera for field use. Although many inspection teams have a digital camera, some teams did not. It was noted in the interviews that teams without digital cameras use 35mm film for photographing conditions and then have paper prints made. Not only does this delay reporting, it hinders the ability to prepare a complete electronic report as the "prints" must be physically pasted into the SIR after printing. The only options for full electronic reporting, using the current paper print process is digital scanning of the final paper SIR or having the 35mm film processed as digital media and inserting these images into the report. No inspection teams used a scanner for transforming paper documents to digital media, nor did any have 35mm film processed as digital images.

Stage 3 - Reporting Process Analysis

Inefficient reporting practices can be eliminated with the implementation of a process in which an inspector can retrieve previous reports on site through a mobile computer. Once the report is accessed in the field multimedia data could be entered directly into the final report and uploaded from the field device to a server through a synchronization process. This process would combine field data collection with report preparation and avoid separate data entry into the three separate programs.

Multiple programs for reporting

A major inefficiency and redundancy within the inspection process involves entering three separate report applications to complete an inspection report. Upon observation there does not appear to be any strengths supporting these reporting methods. Separate data entry for each program is time consuming, at times redundant, and prone to errors. A more efficient method would involve having a gateway entry for reporting all field data. An intermediate process improvement is to develop a "translator" file that automatically transfers inspection data from a mobile computer to the different databases.

For example, a common data field that exists between Pontis and HTRIS are NBIS "coded" condition ratings. Depending on the inspection team this data is either entered in both HTRIS and Pontis by the inspector or is entered in Pontis and then uploaded weekly to HTRIS. Departmentally, weekly auto-uploads are the preferred method. Pontis Version 4.2 has the capabilities to compile all the data, condition elements and multimedia objects into a single electronic report and offers opportunity to be this common "gateway." In effect, all inspection data can be entered directly into Pontis Version 4.2 and then uploaded to HTRIS. A hard copy of the commentary, similar to the CR can be output in a paper format as necessary. Figure 11 shows an abstraction of the current reporting process while Figure 12 shows a restructured method of reporting, distributing, and archiving using mobile computing assistance. The final document is electronically consolidated and can be printed for review by the inspector and engineer and then signed off or it can be viewed electronically and then signed off with digital signatures.

Distribution and Archive

Evident from the analysis is that this portion of the process is adhering to the rules and boundaries of a paper based distribution and archival system. Report distribution and archiving can benefit from an automated and electronically distributed process within an electronically maintained archive. The absence of unified electronic inspection reports perpetuates a cumbersome inefficient inspection cycle and begs for automation.

The major action items that must be addresses in developing digital distribution and report archiving are: 1) compiling the various reporting needs into a single final report; 2) review, approval, and sign off mechanisms on at least two levels; 3) flagging the inspection as complete; 4) distributing the final report to users; 5) protection of the archived report from loss or corruption when reused during the next reporting cycle.

Figure 12 depicts how reporting, distribution and archiving processes are handled electronically through the use of "push/"pull" processes. In a "push" process, an email copy of the file can be forwarded to the designated parties. The report can be printed out or can be read on screen and responded to by email. The "pull" process is actuated by automated sending of an email notification to interested parties that a completed inspection report has been posted online. The email documents and hyperlinks the file's location and its availability. This allows a user to access the report at their convenience. In both "push" and "pull" processes the original document remains archived on a central server. There are several automated email dashboard programs available that will notify designated parties on document availability.

Among features of the current system that retard electronic data integration (EDI) are that photographs when inserted into the SIR remain in an un-cataloged collection of paper and electronic files and folders. One inspection team typically archives a floppy disk of digital images in each paper file folder together with the CR. This makes searching for archived photographs difficult and thus defaults to a reliance on the limited number of photos included within the SIR portion of the CR. An archival data structure for electronic images, photographs and drawings is necessary and should be implemented and placed into practice.

Document "sign-off" techniques can be done electronically with digital signatures or through protected authorization and system acceptance. Embedded coding can allow "un-signing" of a document if it is prematurely signed or conditions occur that nullify a previous endorsement. Flagging a completed report can also be coded within the database and assigned to a "completed inspection" category once the inspection is designated complete.

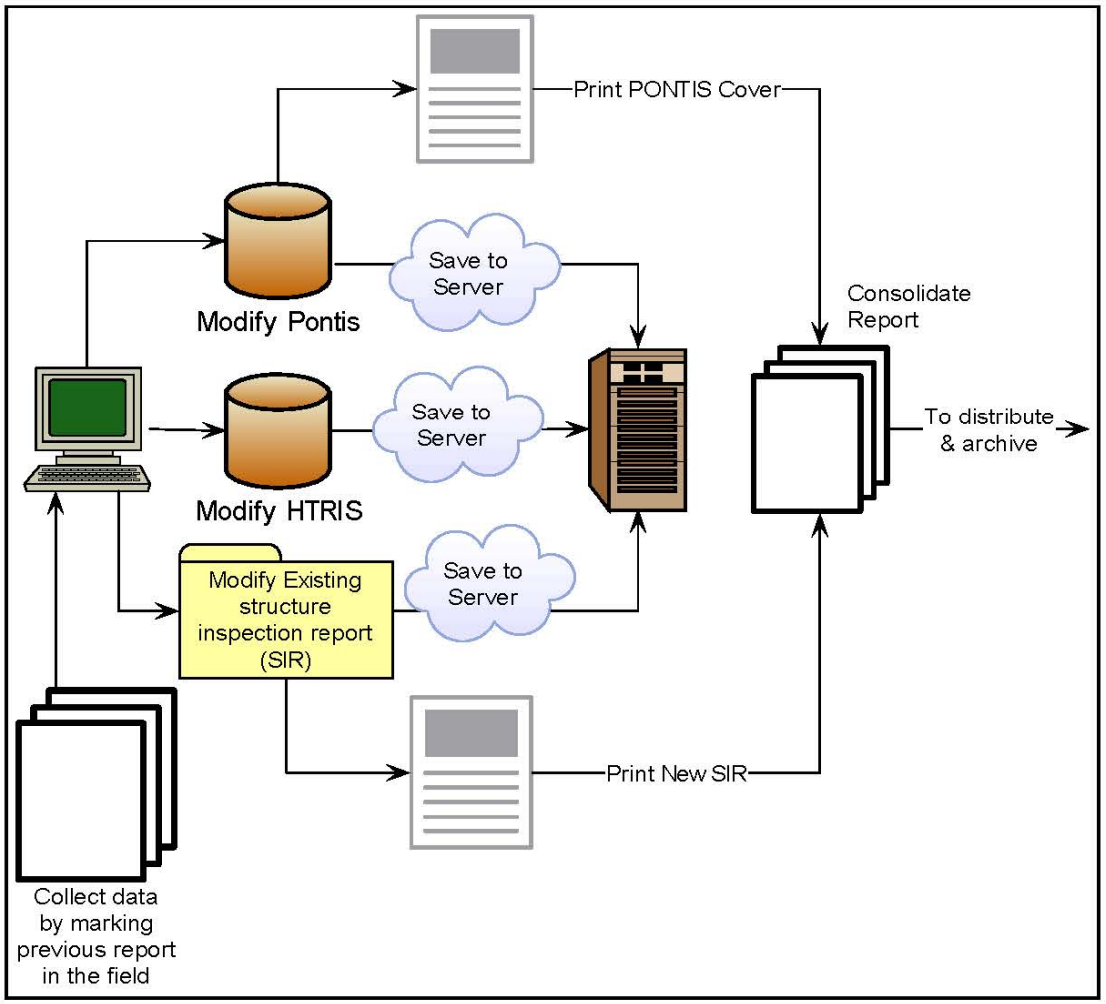


Figure 11 - Current Reporting Stage

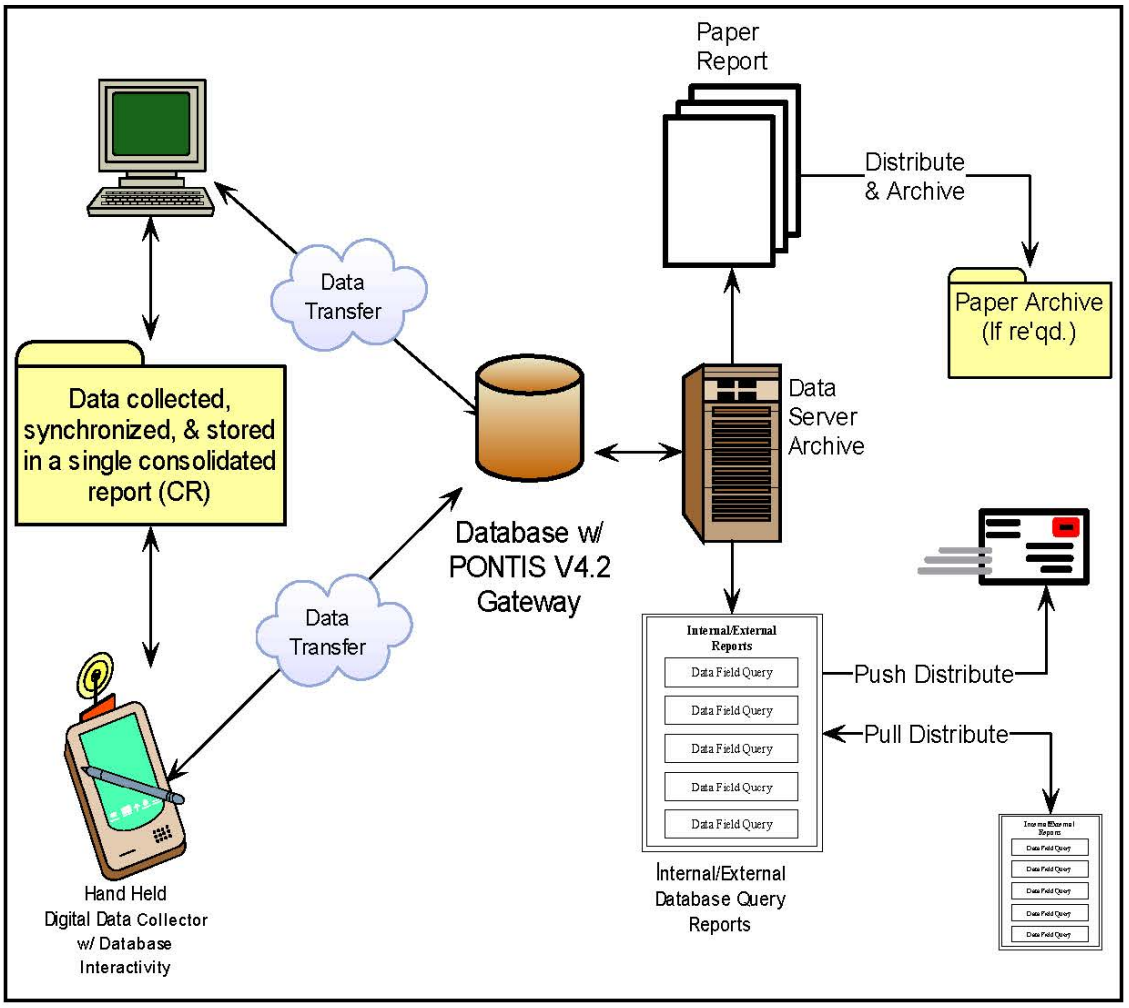


Figure 12 - Alternative Stage 3 & 4 - Reporting Function

Concluding Transformation Strategies and Recommendations

Process improvement can be done incrementally or revolutionized with "breakthrough" strategies. Several process alterations noted earlier will be reiterated and new process improvement strategies proposed. The recommended transformation strategies are presented in a tiered manner to allow incremental improvement while planning and implementing the overall process transformation. The first two tiers are simple process improvements and attempt to assist in process standardization and provide observable improvements to the current process. Tier 3 is a proposed breakthrough strategy that takes the position that mobile computers are essential to transforming current inspection process and will eventuate at some point. Tier 3 improvements intend to diminish current redundancies in data collection, and data entry. Automating standardized processes should improve the efficiency of inspections and make condition information available in a timely manner.

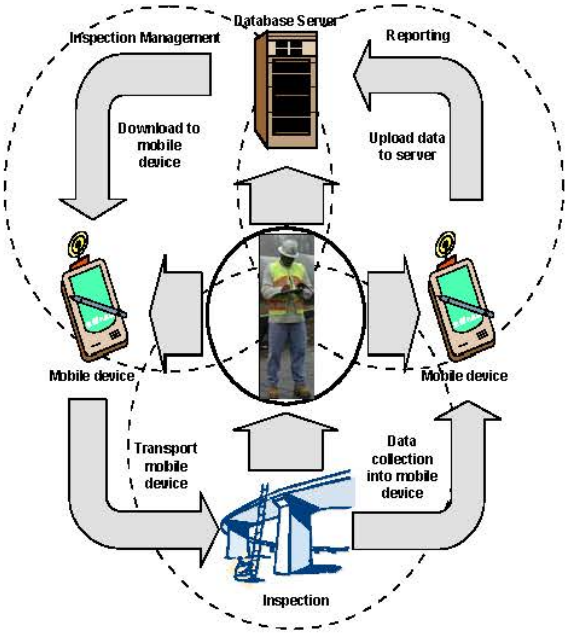


Figure 13 - Inspection Process Transformation

Figure 13 shows a fully transformed Tier 3 inspection process using currently available IT and IT processing tools. This process once transformed should to exhibit the following attributes.

- An enterprise wide information integration
  - Inspection throughput to asset management.
- Mobile data collection devices
  - A robust inspector's field tool
  - Standardized electronic forms, (E-forms)
  - Remote access to central data
- Automated documentation
  - From Inspection Management through Reporting
- Automated cost estimating assistance
- Efficiency in reporting, distribution and archiving.

Understanding Inspection Functions

For process transformational purposes the four inspection stages previously identified are narrowed into three distinct functions. All three functions are considered essential components of the whole inspection process and each must be addressed and integrated into the whole for process transformation to succeed. The basic function of "inspection" is to provide asset information that can feed infrastructure management strategies of analysis, MR&R, and budgets. The closer that process transformation reaches process integration the less distinct many functional differences become. As more functions are automated they become less the resident of one functional area and more a universal adaptation across all functions. This is evident in the following recommendations and is observable in the process maps as they grow more concise and functions begin to overlap as automated solutions are advanced. See Figures 13 and 14 for

simplified and consolidate process maps that show automated processes and cross-functional areas.

Tier 1 Strategy – Internal Inspection Process Improvements

This strategy is incremental only, there is no transformation, and there is no modernization, only improvement. The current practices run like clockwork, these processes are tried and tested and they get the job done. For those who believe, "if it ain't broke, don't fix it," these recommendations aim to improve but not revolutionize the process. While not all inspection functions can be improved by modifying the internal processes, some can be improved and others modified to advance downstream process improvements once a mobile computing transformation is undertaken.

The "Inspection Management" function is clearly dependent on HTRIS downloads for scheduling. Unless VDOT's IT department can adjust the retrieval and sort bottlenecks within the inspections scheduling process, little can be done with this function. The "Inspection and Condition Assessment" and "Reporting" functions do offer opportunities for improvement without agency IT involvement. By addressing the following operational recommendations the inspection process will improve and several bottlenecks can be eliminated. These recommendations are simple administrative tasks directed at improving the process and apply consistency across the Bridge/Structure Division.

Tier 1 Recommendations

1. Issue a digital camera to each inspection team. This issuance should be done as if the inspectors were the cameras owners. Reports indicate that when this "ownership" is offered it reduces "loss, theft and damage" (Fletcher and Marlin, 2003).
2. Mandate that all inspections use digital photography. This preferably done using digital cameras, otherwise any 35mm film must be processed as digital media.
3. Implement a standard cataloging and archiving system for all digital images. There are several software applications that allow server based image archives.
4. Create a master drawing template of stock sketches, bridge plans, structural elements, beams, girders, etc. and other common element characteristics for different bridge types/families. This will aid inspectors in preparing deterioration sketches for inspection reports.
5. Consistently apply the automated uploading of Pontis data into HTRIS. This will eliminate the potential for erroneous information being manually input into one of the databases.
6. Develop a procedure to electronically incorporate a Pontis "cover sheet" into SIR's. These create a single electronic document and eliminate the print and combine approach used to producing a CR.
    a. An available technique is to electronically capture and insert a Pontis screen or report page into the SIR document through Sybase "Infomaker," included with Pontis.
    b. Another technique, that requires dual entry, is to provide additional columns and/or cells in the SIR template for inputting condition ratings, and critical feature

inspections. The same can be done for element condition states, field postings, and traffic safety features, attachments and signatures.

7. Archive the final electronic CR as a .pdf file for protection and distinction between a working report file and an archived file. Incorporate electronic signatures into the archived electronic copy as the "legal" copy.

Tier 2 Strategy – IT Interface Modifications

Tier 2 transformation strategies although incremental have fundamental impacts in the areas of "Inspection Management" and "Reporting." There is some modernization to the process, but the actual "Inspection and Condition Assessment" function would still be conducted with only minor changes. The foundation of the second tier strategy is to interface process modifications within the existing data structures. A move to a single gateway for all field reporting is the obvious direction to pursue. Pontis Version 4.2 has advanced its software with an improved inspection module and the addition of multimedia content links. Although Pontis is not a thin-client application (thin-client meaning the software application can reside remotely) it seems capable as a replacement for the SIR. Specific second tier recommendations may be hindered by the Pontis client distribution process but this is neither researched nor addressed in this report. Tier 2 transformations can be done as a pilot and prototype development program without the acquisition of mobile hardware or personnel redirection.

Tier 2 Recommendations:

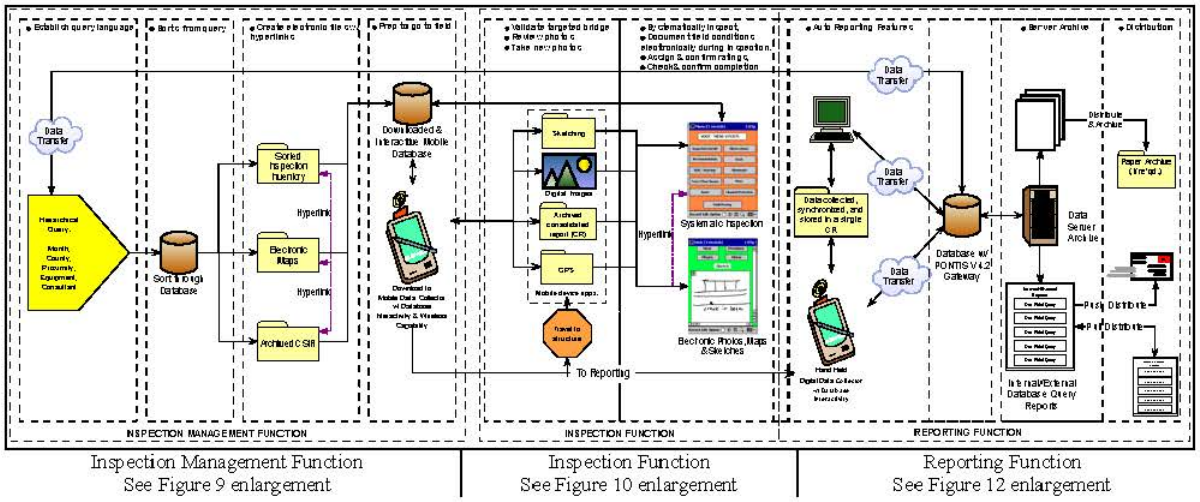
1. Incorporate items 1-4 in the Tier 1 strategy
2. Adopt, implement, and promote Pontis Version 4.2 as the common inspection document format for data collection, data entry and reporting by the inspection teams. This will replace the MS Word SIR commentary with similar Pontis reporting features.
3. Migrate all the field inspections results to a single common database compatible with Palm/PPC's, preferably Sybase or Oracle, effectively migrating away from HTRIS within the Inspection domain. This may already be a part of the agency's overall IT strategy, but it's not evident at the inspector's level.
4. Create access to this common database through a single gateway, preferably Pontis.
5. Customize Pontis with unique VDOT agency data fields, elements, import/export routines not currently internal to Pontis and deemed necessary to assist the field inspection or management mission.
6. Customize Pontis import/export routines to allow "pre-printed, pick and choose" forms for field data collection and reporting. This will assist in data collection and allow an easing into automated reporting.
    a. Pontis now has multimedia capability allowing the SIR to become a customized "form" within the Pontis application. Once the form is completed in the field, the form data can be used to update the central server based Pontis application.
7. Determine if Pontis can also be used for scheduling bridge inspections. Research indicates that the Utah DOT is using Pontis to schedule work, equipment, and resources for bridge inspections (Adams and Stohel, 2002).

Tier 3 Strategy – A Mobile Computing Inspection Enterprise

Tier 3 strategy is to completely modernize and transform the entire inspection process. It eliminates paper processes in favor of using mobile computing for data collection and automating the reporting process. This same process modernization is being pursued at varying levels by other DOTs, notably, Michigan, California, and Florida. Transformation is happening in other states and will happen in Virginia, the only question is when. At the forefront of digitally assisted inspections is the implementation and use of mobile computing devices, either handheld or wearable. The strategy as depicted in Figures 13 and 14 is to automate all processes to the fullest extent using current hardware and software configurations. It is this strategy that should be advanced if VDOT wishes to transform its current inspection processes to higher levels of productivity, accuracy, and timeliness. Figure 13 is a simple concept map with the inspector at the heart, while Figure 14 maps alternative mobile computing processes to the same level of detail as current processes are mapped in Figure 1. Graphical enlargements for each stage in the alternative inspection process are shown in previous figures

"Inspection Management" initiates by running a database query seeking inspection, scheduling, and other support data. The results of this query are automatically downloaded to the mobile device for transport into the field to assist in completing the inspection. "Inspection" initiates in the field with the GPS equipped mobile computer verifying and mapping the previously downloaded bridge coordinates to the bridge's exact geographical location. The verification is stored internally for later uploading back into the master database. Simultaneously with verification of the bridge's location, the mobile device activates the previously download data including, previous inspection reports, completed or scheduled maintenance activities, digital images, sketches, drawings, and other desired data.

The data collection is done through a handheld or body worn computer with IOH, ScanPrint, or a custom data collection application. The mobile computer uses drop down menus, "smart tags," and speech recognition for commands and inputs. Free-hand or menu assisted sketching is done on-screen over template sketches or previously drawn sketches and the sketches stored for upload when the mobile computer is synchronized with the central server. The attached digital camera is used to take standard view, and selected element photographs as prompted by the device. The images are cataloged and stored on the mobile device within linked cells in pre-formatted data collection screens. Data not stored on the device, i.e., manuals, CAD files, etc. but needed because of unique circumstances is wirelessly accessed from a support server and opened on the mobile device.



Inspection Management Function
See Figure 9 enlargement

Inspection Function
See Figure 10 enlargement

Reporting Function
See Figure 12 enlargement

Figure 14 - Alternative Inspection Processes Using Mobile Computing Devices

Upon returning to the office, the mobile computer is synchronized with the agency server and all data collections are uploaded into their appropriate master data fields. Once data is synchronized within the proper data fields, automated report features are activated and pre-configured reports are prepared. The system then changes the bridge status from a pending inspection to a completed inspection. The system then queries the inspector for a list of users to notify by email that the inspection is complete and ready for sign-off. Other users, at their convenience, can access the server from their desktop computer and "pull" down the inspection reports.

To accomplish Tier 3 objectives requires establishment and prioritization of the goals and the intended methods that will contribute to automating the inspection process. These recommendations span from project startup to VDOT acceptance. The research has determined that there are three viable mobile computing opportunities that can move toward implementing mobile computers as field aids in automating the inspection process. It is recommended that all three of these approaches be investigated before adopting a strategy to determine the most cost effective, user friendly and appropriate solution to support VDOT's mission. The three approaches are:

1. Custom software development: develop and trial a customized application that creates robust interactive database linkages between the master database and mobile device. To verify that this was a legitimate option, preliminary handheld database coding was successfully done on PPC's.
2. ScanPrint software: investigate and trial the use of "ScanPrint" as a hardware/software solution;
3. IOH software: investigate and trial the use of "Inspection-on-Hand" as a hardware/software application that accomplishes the same objectives as a customized system.

Tier 3 Recommendations:

1. Research the three proposed approaches, "Custom software development," ScanPrint hardware/software application, and IOH hardware/software application.

2. Agree upon and prioritize the specific objectives that mobile field inspection (MFI) should achieve and the tasks it should enable.
3. Create a MFI application that accommodates ease of field inspections with automated interfaces (synchronized uploads/downloads) to asset inventory (HTRIS or ORACLE) and to the Pontis gateway.
4. Establish a "pilot program" to validate the systems capabilities of each of the three approaches and benchmark their performance specific to VDOT inspection and IT environments. Pilot appropriate solutions through a series of simulated inspection trials.
5. Evaluate vendor and/or programming support for all three solutions.
6. Determine and report which systems and components hold promise for meeting VDOT objectives. Based on this data, update existing and proposed work process maps to provide a guide for overall process transformation.
7. Present the findings and results and secure endorsements and recommendations for continued development.
8. Establish prototype test protocols and procedures, and develop hardware/software product specifications.
9. Create a "prototypical" mobile inspection assistant, including hardware and software.
10. Engage the prototype in field testing to be benchmarked against VDOT objectives.
11. Using results from the prototype field trials, document and report operational deficiencies and potential improvements,
12. Recommend product specifications for next iteration of the mobile inspection assistant and determine deployment and adoption strategies.
13. Procure hardware and software configured to meet the prescribed specifications.
14. Implement a small scale pre-adoption field trail program targeting 8-10 inspection teams.
15. Execute adoption strategy. Monitor and record the mobile inspection assistant's acceptance, and its contribution to performance improvement.

The technology is available and the time has come for implementing a strategy to transform the inspection process from a paper production to a digitally enhanced process by using mobile computing for electronic data collection, automated reporting and synchronizing data uploads.

REFERENCES

Advitam Group. *2002 Mackinaw Bridge Annual Inspection*. 2002. http://www.advitam-group.com/tools/pdf/scanprint_mackinac.pdf. Accessed June 2003.

Advitam Group. *ScanPrint Product Guide*. 2002. http://www.advitam-group.com. Accessed August 2002.

Adams, D. and R. Stohel. *Utah Department of Transportation Presentation*. 2002 Pontis Users Group Conference, 2002. http://aashtoware.camsys.com/docs/utahPontis2002.htm. Accessed June 2003.

Elzarka, H. and L. Bell. Development of Pen-Based Computer Field Applications. *Journal of Computing in Civil Engineering,* April 1997, pp. 140-143.

Elzarka, H., L. Bell and R. Floyd. Automated Data Acquisition for Bridge Inspection. *Journal of Bridge Engineering*, Nov. 1999.

Fanous, F., L. Greimann, and A. Soni. Automated Methods for Collecting Bridge Inspection Data in the Pontis Format, *1996 Iowa Semisesquicentennial Transportation Conference,* 1996. http://www.ctre.iastate.edu/pubs/semisesq/session5/fanous/. Accessed August 2002.

Finley-McNary Bridge Engineering, http://www.finleymcnary.com/project23.htm, 2003. Accessed June 2003.

Fletcher, D. and C. Marlin. Field Applications at DTE Using the Pocket PC. *7th Annual Conference & Exhibition – GITA 2003. Geospatial Information & Technology Association (GITA).* 2003. http://www.gisdevelopment.net/proceedings/gita/2003/mobile/mobil45pf.htm. Accessed June 2003.

Irving, R., and L. Anderson. Speech, the Final Frontier at Virginia Department of Transportation! Virginia Department of Transportation, 1999.

Le Diouron, T. and J. Stubler. Efficient Management of Inspection and Monitoring Data for a Better Maintenance of Infrastructure. *Proceedings of the 1st Congress on Concrete Structures in the 21st Century*, Osaka, Japan, July 2002.

Leung, A. Perfecting Bridge Inspecting. *Civil Engineering*, March 1996, pp. 59-61.

Maxim/Dallas Semiconductor Corp. http://www.ibutton.com/ibuttons/index.html. 2002. Accessed June 2003.

Nathwani, S., A. Shroff, G. Romack, and M. Rice. PBA-Based Field Data Collection for Pontis. *International Bridge Conference*, Pittsburgh, PA, 1995.

Nathwani, S., and A. Shroff. Effective Bridge Maintenance Using Multimedia and Mobile Systems, Sixth *International Conference on Structural Faults and Repairs*, London, England, 1995.

National Bridge Inventory - Virginia. 2002. http://www.nationalbridgeinventory.com/nbi_report_200246.htm. Accessed January 2003.

NBIS 23. National Bridge Inspection Standards, 23 CFR 650.3. 2002.

ProVoxTechnologies, Corp.. *TalkNotes Brochure*. 2000. http://www.provox.com/pdfs/talknotes_brochure.pdf. Accessed March 2003.

Sawyer, T. Putting Field Notes in Context. *Engineering News-Record*, http://www.enr.com, March 4, 2002. Accessed March 2002.

Sunkpho, J. and J. Garrett. MIA: A Wearable Computer for Bridge Inspectors. *Second International Symposium on Wearable Computers*, Pittsburgh, PA, October 19 - 20, 1998. http://www.computer.org/proceedings/iswc/9074/9074toc.htm. Accessed October 2002.

Trilon Inc. *Inspection On Hand (IOH), User's Manual, Version 3.4*. Trilon, Inc., Upper Darby, PA, 1999. http://www.trilon.com/trilon/ioh/docs/IOH_v3.4. Accessed March 2003.

Trilon, Inc. Upper Darby, PA. http://www.trilon.com/trilon/, 2002. Accessed September 2002.

Trilon, Inc. Upper Darby, PA. http://www.trilon.com/trilon/ibiis/ibiis.htm. Accessed September 2002.

Yabuki, N., K. Tomita, and Y. Shimada. An On-Site Inspection Support System Using Radio Frequency Identification Tags and Personal Digital Assistants. *International Council for Research and Innovation in Building and Construction, CIB w78 Conference 2002.* Aarhus School of Architecture, Copenhagen, Denmark, June 12-14, 2002.

APPENDIX

Lynchburg District Inspection Process

A bridge inspection for the Lynchburg inspector is a multi-step process which is divided into three stages: planning, inspection, and reporting.

Inspection Management

The frequency at which a bridge is to be inspected varies, however the general standard set forth by the NBIS is two years. The bridges are sorted according to: available equipment, consultant, month, county, and team leader. Some bridges require an outside consultant and the process which the consultant undertakes their inspection is not documented in this report. For an in-house inspection, the inspector will make a map for the inspection period, pull the previous bridge inspection reports, and travel to the bridge site.

Inspection and Condition Assessment

Once at the site, the inspector will verify that he or she is inspecting the correct bridge by identifying the structure number painted on the structure, and verifying that the previous bridge photos match the structure. The inspection proceeds with the aid of standard predefined categories identified in Table A1.

Table A1 - Inspection Categories

Types of inspection	Points of inspection
Approaches	Checked for vertical alignment and slopes
Decks	Checked for wearing surfaces
Superstructure	Check beams, surfaces, and plates
Sub Structure	Check pier caps, columns, undermining and slopes
Signage	Check for required signs
Channels	Check for debris, flooding, changes in the channel

The superstructure of the bridge including the condition of the beams, surfaces, and plates is inspected and documented. A deck inspection is a visual process; however some aspects of the deck inspection include chipping away at the foundation to see the condition, as well as conducting a sound check, by tapping elements with a hammer. The substructure of the bridge is also inspected and this generally includes inspecting pier caps, and a slope inspection. A channel profile must be conducted which includes checking for a change in topography, making a sketch of the abutment, and a vertical clearance inspection is made as necessary. Based on the daily traffic count and other conditions the inspector will ascertain if the bridge as a whole is fatigue prone.

The superstructure, deck, substructure, and channel, all receive condition ratings ranging on a scale from 0-9. All new work completed since the last inspection is reported. Any bridge deemed from observation in a critical state requires immediate completion of a critical report. Still 35mm photographs of the bridge are taken and new sketches drawn or existing sketches modified. The inspector notes what was observed during the inspection and also makes

recommendations and gives an overall assessment of the structure. Before leaving the site all obvious HTRIS inventory changes are verified and the inspector will check and clarify all recommendations.

Reporting, Distribution and Archiving

At the office, if required, an expansion dam inspection report, or a posting report is filed, otherwise the HTRIS database is accessed and all pertinent information is entered, such as the condition ratings, traffic safety, inspection date, and inventory changes. After entering the required data, the HTRIS database is exited and the Pontis database is entered. All required data is entered into Pontis including quantities, conditions, and elements. A Pontis report is generated and Pontis is exited. The MS Word report program, from which the previous report was pulled, is entered. Modifications such as inputting CAD drawings are made to the previous report

After all modifications are performed on the previous report, a new inspection report is generated and saved and is consolidated with the Pontis report, the HTRIS update, and any other reports that were necessary for the particular bridge. The CR is reviewed and distributed to the District and Central Offices and to the Residency. Upon reviews and revisions of the final report, five copies of the report are generated and one copy is given to each of the following offices: District, Central, and Residency. One copy is retained to be used as a field copy for the next inspection. Another copy is placed in the master inspection file.

Staunton District Inspection Process

A bridge inspection for the Staunton District is a multi- step process which is divided into three stages: planning, inspection, and reporting.

Inspection Management

The bridge inspection process begins with the inspector self-scheduling every 90 days from a list of inspections located on the HTRIS database. The inspector will select the bridge to be inspected according to the following criteria: monthly, multi-county, availability of equipment, and accessibility. Once the bridge to be inspected is chosen, previous copies of the building and structure inspections are pulled from the previous report folder. The inspector travels to the bridge site carrying a working copy of the previous inspection along with any needed tools or equipment for the inspection.

Inspection and Condition Assessment

Once at the site, the inspector will verify that he or she is inspecting the correct bridge by identifying the structure number painted on the structure, and verifying that the previous photos match the structure. The inspection proceeds with the aid of predefined categories identified in Table A1. If the bridge is new, an inventory template is completed to fill all needed HTRIS inventory information. Upon completion of the bridge inspection, critical issues are reported to the Residency as soon as possible, and an overall condition assessment of the bridge is reported. After giving the bridge an overall rating and finalizing the condition assessment, the inspector returns to the office.

Reporting, Distribution, and Archiving
If a posting problem, which is considered second level critical, was noted during the inspection, a posting problem report is completed upon return to the office. The posting report is analyzed and separated within its own program and flagged. The posting problem is later addressed by the district safety engineer.

If a posting problem is not observed during the bridge inspection, upon return to the office, the inspector will set folders aside for later reporting. When time permits the folders are pulled and the inspector will begin the final report by entering MS Word. Upon finishing the MS Word report, the 35 mm photos and the redrawn hand sketches are pasted into the MS Word document. After completing the Word report, Word is exited and, Pontis is entered. Pontis will automatically update HTRIS with the condition ratings, quantities of deterioration, traffic ratings, year painted, and next inspection date. The previous Pontis report is updated to generate a new and accurate Pontis report. Upon completing the Pontis report, the Pontis database is exited and the HTRIS database is entered. All changed inventory data within HTRIS is manually updated. After updating the HTRIS database, the MS WORD report and the Pontis report are consolidated and the result is the most recent bridge inspection report. The secretary makes three copies of the new report. The District, Residency, and the Central Office each receive one copy and the original copy goes back to the master bridge folder from which previous reports were pulled.

Hampton Roads District Inspection Process

A bridge inspection for a Hampton Roads bridge inspector is a multi-step process which is divided into three stages: planning, inspection and reporting.

Inspection Management:
The inspector begins the process by self-scheduling from a 90-day inspection schedule. HTRIS is the source database that is used to extract the 90 days worth of bridges due for inspection. The selected bridges are then prioritized for inspection based on the quantity in a particular county, the critical equipment needed for the inspection, the availability of that equipment, and those bridges that require special inspections. Once the bridges are selected and prioritized, the inspector will create a monthly list from which he or she will work. When the bridges are selected, the inspector will manually retrieve a copy of the previous inspection report from the bridge file folder.

Inspection and Condition Assessment
Upon arrival at the bridge site, old reports, landmarks and mile markers are used to verify the bridge location. Certain aspects of the inspection can be done visually, meaning that the condition of the structure can be determined by simple direct observation. Visual inspections include noting alignments, shifting, and any clearly identifiable damages. Bridge areas that must be inspected include: approaches, decks, superstructures, substructures, channel profiles, and signage, various aspects of the inspection can be seen in chart form by referring to Table A1.

Approaches must be inspected for vertical alignment and abnormal slopes. A deck inspection requires both a visual and a physical inspection. The deck of a bridge must be checked for wearing surfaces, such as potholes, and uneven pavement. An inspection of the superstructure of

a bridge includes inspecting its beams, surfaces, and plates. The inspection of the substructure of the bridge includes inspecting the pier caps, columns, undermining and slope inspection. The inspection of the channel profile requires both a visual and a physical inspection. A probe is utilized to determine the condition of the channel. Two inspectors are required for the process, one retrieves and calls out the data collected while the other records. A signage inspection is required for a posted weight limit bridge. After completing the various inspections, the inspector will either return to the office or travel to the next scheduled inspection.

Reporting, Distribution and Archiving

Upon arrival at the office, preparations are made to generate a new inspection report. Data from the bridge inspection is entered into an MS Word commentary report with associated graphics, including sketches and photographs. After data entry into the Word Report, the MS Word software application is exited, and the Pontis program is entered. The bridge structure is located within the Pontis database using the county and Pontis bridge codes. Upon locating the structure within the database, all required information is reported. This includes the bridge NBIS rating, and the maintenance and repair quantities. If the bridge is a new structure all the inventory information must be entered. After entering the required data, the Pontis program is exited and the next inspection date is generated. The Pontis program is reentered to verify that the data has been accepted. The data from the Pontis database is uploaded to the VDOT server by IT.

The HTRIS database is reentered for the purpose of updating the inventory. Factors such as length of bridge, average daily traffic, width of bridge, and needed repairs are all entered into the HTRIS database inventory. Data from the HTRIS database is extracted for an in- house MS Access database (ordinary and maintenance). After data entry into the HTRIS database, the data recorded in HTRIS is filed until the next 90-day report is due. If a sign is missing from the bridge, a sign report must be completed. Upon completion of all applicable reports, copies of the reports are sent to the Structure and Bridge Division, the Residency, and a copy is retained by the District.

Salem District Inspection Process

The bridge inspection process in the Salem District is a multi-step process which is divided into three stages: planning, inspection, and reporting.

Inspection Management

The Salem District bridge inspector begins his or her inspection process by scheduling their bridge inspections from a 90-day "to do list" which is generated by HTRIS. The HTRIS database serves as bridge inventory which includes information such as bridge elements, construction types, and frequency of bridge inspection. The standard for bridge inspection frequency is every two years according to the NBIS. The HTRIS database also contains information on bridges that require special inspections, signage inspections, and new bridge inspections. Non – scheduled emergency inspections are not retrieved from the HTRIS database being that they are unexpected and generally need to be attended to promptly.

The typical process for periodic inspections is to select bridges for inspection by prioritizing the bridges according to month, county and equipment. Once a bridge has been selected for inspection, the location of the bridge is manually marked on a county road map and previous inspection reports are gathered and placed in an active queue and taken to the bridge site when an inspection is to be made.

Inspection and Condition Assessment

Once at the site, the bridge is inspected according to the categories, approaches, deck, superstructure, substructure, and channel, as identified in Table A1. While on site, the inspector reviews and writes all new observations on a copy of the previous report. The inspector also notes and verifies that the previous recommended work has been completed. Photographs are taken and sketches are made of the structure. Additionally the inspector must designate a sufficiency rating and determine if additional reports such as a structural analysis, posting report, critical report or if any other additional reports are required. If the sufficiency rating is < 80 the inspector creates a "tickler" notation for a reminder action. Before leaving the site an in-field review of the data gathering is conducted among the team members. This review checks inventory data for omissions, confirms maintenance and replacement funding amounts. All data collection is then placed within the file folder and the inspector proceeds to the next inspection or returns to the office.

Reporting, Distribution, and Archiving

The inspector begins the report by entering Pontis, and recording NBIS ratings including condition ratings, elements, and quantities. After relevant data is entered into Pontis, the database is exited and the MS Word report template is opened to create a bridge commentary inspection report. This bridge inspection report contains verbal commentary, digital photographs and/or 35mm photographs of the bridge and maintenance cost estimates. The Bridge Inspection Report, the Pontis Report, and any other reports such as critical, posting, expansion dam and structural reports are consolidated and placed into a single folder. The team leader reviews and signs off upon completion of the consolidated reports. The secretary checks report data including categorizing the reports based on their county location and their condition ratings. The ratings are further reviewed by the District engineer who will take actions required as a result of the inspection. A copy of the final consolidated report is forwarded to Central Office, District Office, Residency and the inspector.