

Reengineering the Bridge Inspection Process to Enable a Knowledge Management Solution

FRANK P. DICESARE

Merrill Clark, Incorporated

PAUL DEMERS

GIS/Trans, Ltd.

ABSTRACT

The upcoming implementation of bridge maintenance systems (BMSs) by all state Departments of Transportation (DOTs) has resulted in a paradigm shift in maintenance planning for bridge repair. Reduced maintenance budgets have resulted in funding for bridges in an emergency state taking precedence over routine maintenance. A bridge management system must assist an agency in determining the optimal time to exercise improvement actions on a bridge given the funds available. The objective to adopting such a system is to improve the overall condition of an agency's network of bridges, emphasizing the need to maintain the condition of a bridge before lapsing into an unsafe state.

A key point in the implementation of a BMS is that the analysis the system provides is only as good as the information that is input into the system. Very little work has been done on how to narrow the gap between the data required for the models and current inspection processes.

The gap can be narrowed by a bridge inspection solution that is the result of reengineering the inspection processes. Through reengineering, all non-value added steps in the 'Current' inspection processes are eliminated in the 'To Be' processes. The 'To Be' processes are enabled by a knowledge management based bridge inspection solution that integrates the following components: Enterprise Document Management System and Electronic Forms.

INTRODUCTION

The term knowledge management (KM) is used extensively across many industries. One commonly accepted definition is delivering the right information to and from the right people at the right time. In practice, KM is a process where multifunctional departments can work together, supported by Enterprise Document Management System (EDMS) and Electronic Form applications (E-Forms), to capture, review and approve mission critical unstructured (content based bridge inspection report) information. Once approved, this unstructured information through the use of an embedded business rule will automatically update the structured information in the National Bridge Inventory (NBI) database.

Improving quality was the initial driving force behind the development of knowledge management solutions. With increasing competition for resources, companies began looking closer at KM and realized that the technique was more than a way to improve quality. It became evident that if a system approach (document life-cycle control)

was applied to KM the concerns of cost and delivery/completion time could also be attacked. This approach provided the capability to address the three areas of quality, cost and delivery time.

The goal of achieving a knowledge management environment can be divided into two major areas. The first is the vision of a physical program architecture that will enable the operational aspect. The second is the development of information models that will identify potential KM solutions, the vision of an information sharing/data integration environment. The first major area, a KM physical program architecture that will enable the operational aspects of an automated bridge inspection KM solution, is complex and constructed by the integration of two major KM technology components (EDMS and E-Forms).

KM PHYSICAL PROGRAM ARCHITECTURE

To envision a KM physical program architecture the IS executive has to understand that two distinct information worlds exist in every enterprise: the structured and unstructured. The structured world is filled with data and data driven applications [purchasing and engineering (load analysis, etc.) applications]. The unstructured world is diametrically opposite and is filled with documents (inspection reports, bridge drawings, seismic data sheets etc.), usually paper based. The challenge facing IS executives is to envision a KM physical program architecture that will bridge these two disparate worlds.

The two key components that make up a KM architecture are an EDMS and an Electronic Forms application. The heart of an EDMS is the document repository that should be built on an object/relational database foundation. One of the strengths of an EDMS is that the system is built integrating the best of five different technologies to provide the most flexible and powerful KM infrastructure.

Object technology provides rapid application development paradigms, reuse of objects to gain productivity, inheritance models to allow for easily extending the system to match unique business requirements and an Application Programming Interface (API) that is easy to work with.

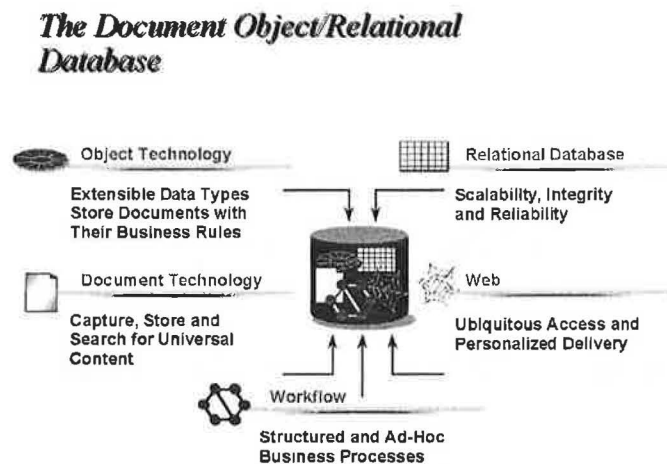


Figure 1: Document object/relational database.

Relational technology has always provided a very scalable and high-performing infrastructure for managing structured data, which an EDMS uses to store metadata and relationship information. The EDMS will have document-specific capabilities and infrastructure to allow for things like querying for content of documents, searching virtual document structures, navigating and managing relationships, etc.

The EDMS Document Server Software's built-in workflow enables team members to coordinate and control the document life-cycle process involved in creating a new document, submitting the document for review, reviewing a document, submitting the document for approval, approving a document, effective document state, historic document state and archived document state. Document coordinators can define and manage workflows for a wide variety of processes such as design, construction, inspection and maintenance. Team members can access an approved list of workflows based on established business processes or they can route documents for review on an ad hoc basis. The system uses an existing e-mail system for automatic notification of team members who are impacted by key events associated with the document life-cycle process.

The web has provided a key platform for information delivery with cost-effective benefits—the EDMS will take advantage of this by extending document management to web browsers. This capability will allow collaboration between bridge inspectors, remotely located in field offices throughout a state, and supervising engineers at a DOT's headquarter office during the document life-cycle process associated with a bridge inspection report.

An EDMS will store everything as objects. This means that documents (inspection reports), each version of a document, workflow routers, Programming procedures, saved queries and more are all stored as Document Objects. This allows the EDMS to then provide many of the capabilities we already discussed, such as unique attributes on each version of a document, reusing components in Compound Documents, managing relationships between pieces of information, etc. Each Document Object can be versioned, including things like business processes and queries.

Document Objects really have two key areas of information within them: the structured information (metadata) such as owner, location, last modify date, status, security and so on; and the actual content of the object itself. With an EDMS storing the content separately from the metadata, it can manage content of any type, including simple or rich text, audio, video, images, etc. This is a real strength of an EDMS.

The EDMS must provide a multi-tier architecture that allows you to leverage your existing infrastructure and will scale as your deployment grows to meet your needs. At the bottom-most level is the Document Object/Relational Database, which is really a virtual collection of the relational database, the operating system, full text indexes and content storage. Other than the operating system, each of these can be on a separate machine if needed for scalability and performance reasons. At the next level up is the Document EDMS Server Software, which provides the application services needed for any EDMS application or product. The Document EDMS Server Software processes all user requests, enforces security, does connection management, optimizes communications to eliminate bottlenecks and all other application based logic.

For web clients, the EDMS Web enabled software is next in the layers of infrastructure, working with the Web server to deliver information to and from web browsers. And ultimately, the last tier is the user and their client application. This

multilayered infrastructure is meant to balance the load of processing between different machines, thereby producing high performance and responsiveness, as well as scalability.

The EDMS client software delivers the appropriate EDMS Document server software functionality to the different classes of enterprise users. The integration of an e-form application with the EDMS client software provides version control and access to business critical bridge inspection reports. Accessing the wrong inspection report, or an outdated version, can have major consequences for your business: rework, lost days, and even thousands of dollars in penalties. With an EDMS, inspection report forms are stored and managed by the powerful Document/Object repository. E-form users (inspectors, senior engineers or supervising engineers) can access the repository via the EDMS client software user interface to retrieve the most current version of the inspection report they need.

The main issue with developing an automated bridge inspection application has been a three-fold concern:

- Form Management
- Data Management
- Information Management

The solution is the integration of an E-form application with a scalable EDMS. The features and benefits derived from this integration can be categorized against the above concerns. Form management is provided with the library services (check-in/check-out) of the EDMS by storing all the inspection report template forms in the EDMS repository. By storing the template forms within the EDMS repository, the EDMS provides version control to the template forms and maintains all versions of the template forms. Data management is also provided with the library services (check-in/check-out) of the EDMS by storing the filled-in inspection report forms in the EDMS repository. By storing the filled-in inspection reports within the EDMS repository, the EDMS can now provide version control to the data collected within the form. This feature ensures that the correct version of the data within the inspection report is always being used. Information management is provided through the proper exchange of information. The data within the inspection report participates in the logic of the business process. This provides an environment where real time decisions dependent on inspection report data are seamless to the users.

With the E-form/EDMS integration's built-in workflow, a DOT can automate all the bridge inspection based processes. Inspection team members can complete intelligent inspection reports on line. The EDMS workflow moves each inspection report through the review and approval process using an existing e-mail for notification and the E-form application can also manage approvals electronically. Through the use of Open Database Connectivity (ODBC) drivers, that are part of an E-form application, the bridge content data that is embedded within an inspection report template can be posted automatically, upon approval, to a bridge management system such as PONTIS.

The illustrated KM program architecture requires a cultural change, a paradigm shift, in work methods (the way work is done) to be successfully implemented within an organization.

DOT KM INFORMATION MODELS

A knowledge management environment can be achieved by adopting the methodology and structured approach of process reengineering. This is the fundamental rethinking and the redesign of an entire process, including jobs, organization, structure, management systems, and values and beliefs, to achieve dramatic improvements in critical measures of performance. To implement process reengineering effectively, a standard methodology must be embraced that is supported by an information-engineering-structured approach. One methodology that has been successfully utilized consists of the following five-step process:

1. Analyze the 'current' environment
2. Establish a 'to-be' environment
3. Analyze the difference between the two environments
4. Develop a migration strategy
5. Develop an implementation plan

This methodology when supported by an information-engineering-structured approach results in the development of the following information models shown in Figure 2. The Process Block illustrates the structured process modeling technique called IDEF0. This technique is a method designed to model the decisions, actions, and activities of an organization or system. As an analysis tool, IDEF0 assists the modeler in identifying what functions are performed, what is needed to perform those functions, what the current system does right, and what the current system does ineffectively.

Interactive JAD sessions are held to create precise process models based on four modeling dimensions:

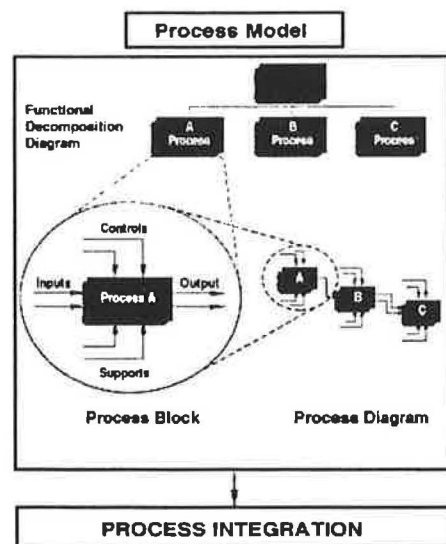


Figure 2: Structure approach models.

- **PROCESSES:** Those functions, tasks, and activities performed in the processes.
- **INPUT/OUTPUT INFORMATION:** The information consumed, transformed, and produced by the processes. Information, so depicted, establishes the connectivity between processes.
 - **CONTROLS:** “Governing” information that controls or constrains the implementation of the department processes. This information includes policies, procedures, and rules.
 - **SUPPORTS:** The organizations, support programs, and tools (e.g., computer applications) that are actually the facilitator or performers of the processes.

The methodology and structured approach defined above were successfully applied to nine bridge inspection processes within Connecticut Department of Transportation’s (ConnDOT) Bridge Safety and Evaluation Unit. This paper will take a close look at three of the processes:

- Bridge Inspection
- Bridge Inspection Report Review/Approval
- Bridge Maintenance Memo Review/Approval

Bridge Inspection Process ‘Current Environment’

Inspectors prepare for a bridge inspection by reviewing the previous (cycle’s) report. An inspection report consists of data collection forms, field notes, sketches and photographs. Inspectors take photocopies of this information into the field to use as a baseline for the current inspection. Photocopying works well for all of the inspection report except photographs. The use of digital cameras has been implemented for approximately 9 months.

During the inspection, changes in the bridge’s condition are marked on the appropriate data collection forms with a pencil or pen. New information, such as photographs and field notes, are taken as well, to support the inspection report. Table 1 lists the data collection forms, their purpose, and when they must be completed.

Only the BRI-18 form is in electronic format. The inspection teams return to their field office at the end of the day and update the electronic BRI-18 form using a laptop and a dbase 3+ application. Once the electronic BRI-18 is updated, they copy the file to a floppy disk and print a hard copy of the updated form. The hard copy of the BRI-18 is signed by both of the inspectors and added to the inspection report. The floppy disk and the new inspection report are hand-delivered to the team’s senior engineer for review.

Table 1: Current Forms for Bridge Inspection

Form	Purpose	When Must it be Completed?
1. BRI-18	Inspection form	Every inspection
2. BRI-19	Federal inventory form	Every inspection
3. PONTIS Elements	Alternate inspection form	Every inspection
4. BRI- 25	Federal inventory form for state routes that travel under bridges	If a state route travels under the bridge. Collected in conjunction with the BRI- 19
5. Joint Measurements	Measure space between joints on a bridge	Depends on bridge. Frequency may differ from inspection date. (approx. 2500 bridges)
6. Seismic Data Sheet	Seismic sensitivity	Depends on bridge. (approx. 2500 bridges) One time inspection
7. Fracture Critical	Fracture sensitivity	Depends on bridge
8. Photo Log	Describes photos taken along with the negative numbers	Every inspection
9. Pin & Hanger Measurements	Measure and monitor pin and hanger connections	Depends on bridge. (approx. 60 bridges)

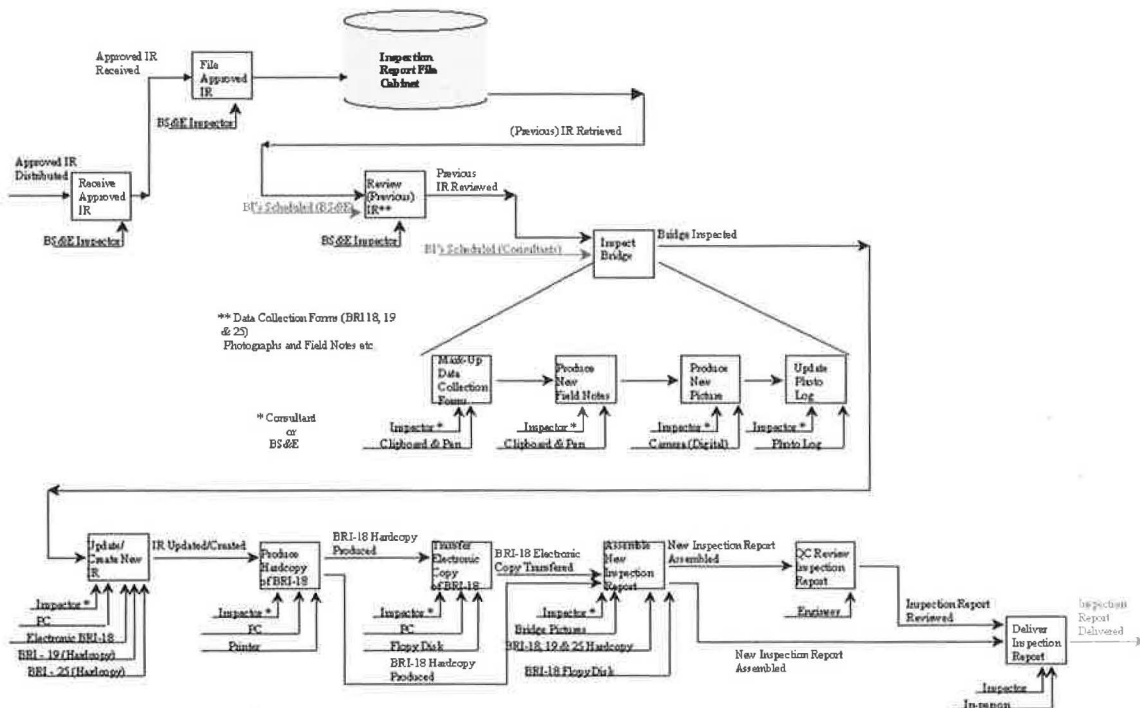


Figure 3: Current bridge inspection process.

maintenance items are necessary. He may agree with all of the maintenance items, some of them, or none. If maintenance is necessary, he creates a word processing file called a bridge maintenance memo, which lists and assigns a priority code to each maintenance item.

The BMM is printed and included with the inspection report that is sent to the BS&E office. Once at the office, a supervising engineer reviews the inspection report and determines whether the maintenance items on the BMM are necessary. Any unnecessary items are crossed off the BMM. If there are maintenance items they agree with, the inspection report is forwarded to the manager of BS&E for final review. The manager of BS&E reviews the inspection report and determines whether the maintenance items on the BMM are necessary. Any unnecessary items are crossed off. An administrative assistant then records maintenance items, which have passed final review, on a new BMM. She prints the new BMM, assigns it a sequential number, and gives it to the manager to sign. The signed BMM is sent to the ConnDOT Office of Maintenance and Highway Operations, Division of Bridge Maintenance. The Division of Bridge Maintenance breaks the maintenance items assigned on the BMM into commitments that its teams complete. Once all of the commitments have been met, they notify BS&E via a memo. There is a need to communicate completed maintenance commitments back to the BS&E when an item is completed, not waiting for all the commitments on a BMM to be met first.

The administrative assistant tracks the progress of BMM's in a log book and a dbase IV database on her PC. She enters identifying information into each when the BMM is assigned and updates each with the date the commitments were met by the Division of Bridge Maintenance. A staff member in the Division of Bridge Maintenance is responsible for tracking the progress of the maintenance items assigned by BS&E versus the commitments assigned by Bridge Maintenance.

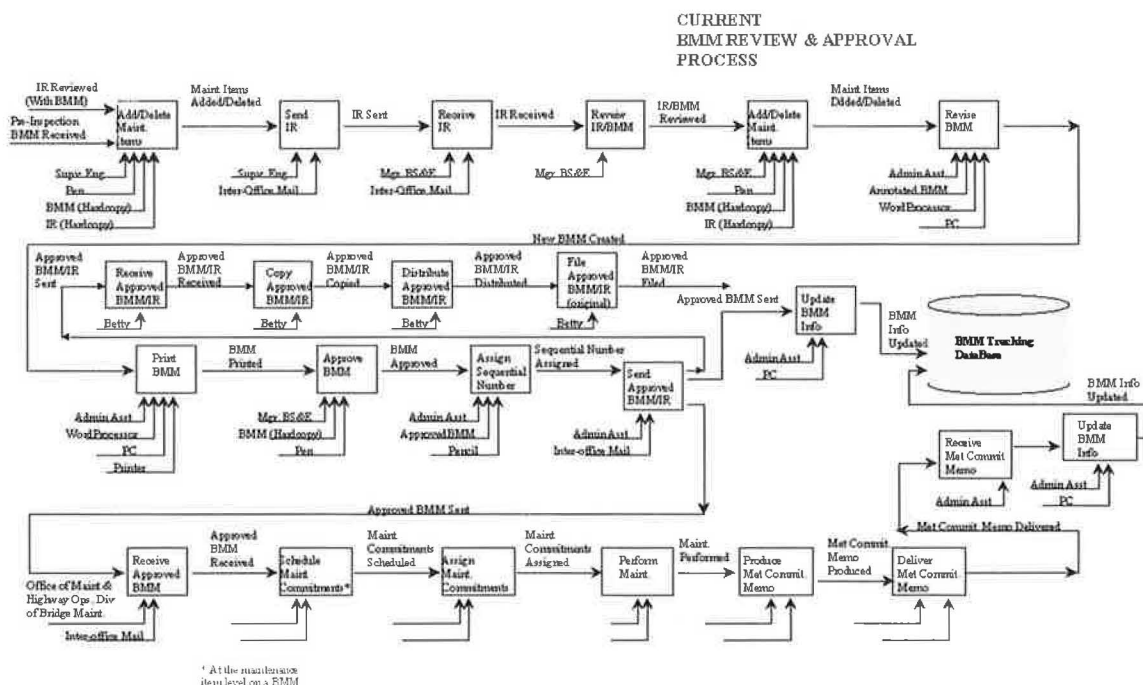


Figure 5: Bridge maintenance memo review/approval process 'current environment.'

Bridge Inspection & Review/Approval Process 'To-Be Environment'

See Figure 6 for the To-Be Bridge Inspection/Review and Approval Process. The inspector will log-in to the ABIP at either a client or intranet seat and be presented with a view of the ABIP database (cabinets).

He/She will then:

1. select the appropriate cabinet and folder and view the inspection report and related documents.
2. print the contents of the folder, the inspection report, field noted, maintenance memos and photos.
3. take the printed contents with him/her into the field to perform an inspection.

While conducting the inspection, the inspector will mark-up the previous inspection report, produce new field notes and take new photos.

Upon returning to the district office he/she will:

1. import the digital photos into the local PC directory.
2. check-out the current photos.
3. select the ABIP check-in from file.
4. check the new photos into the ABIP from the local directory. (This function will replace the previous bridge photos with the new photos.)

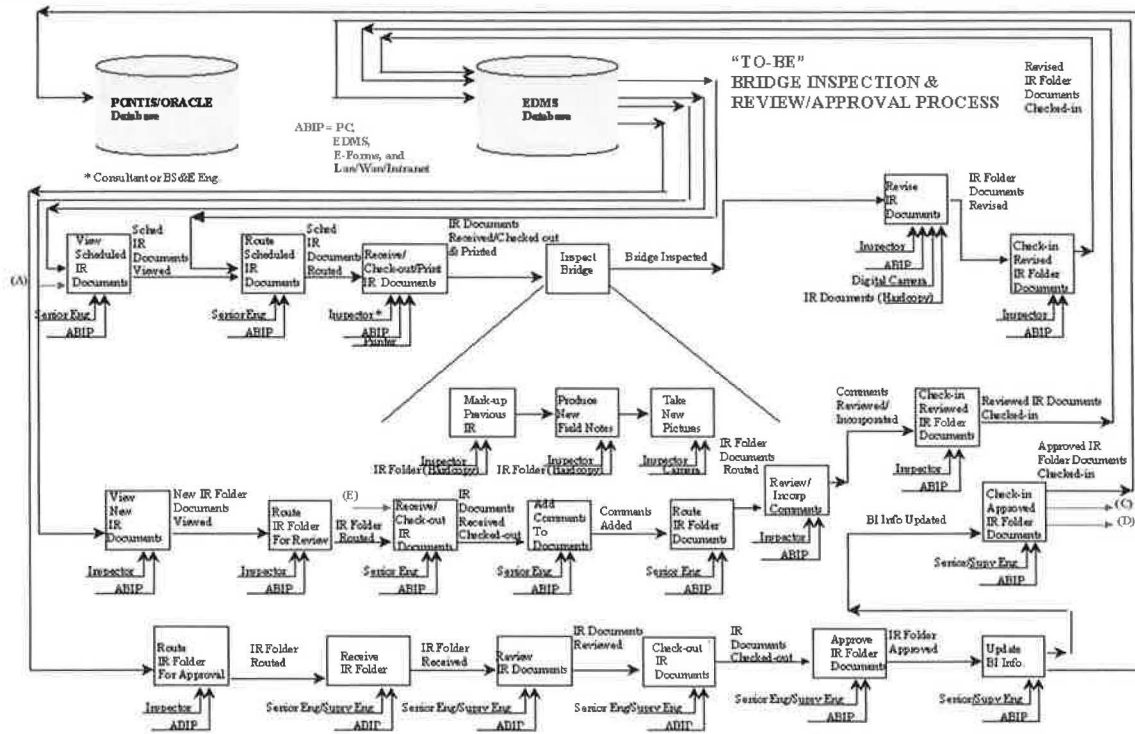


Figure 6: Bridge inspection and review/approval process 'to-be environment.'

The inspector will then:

1. edit the current inspection report by “unsigned” it and revising it with the information captured during the inspection on the hardcopy annotated inspection report (taken into the field with the inspector).
2. update any field notes that were transcribed during the inspection process.
3. sign the inspection report and check it back into the ABIP designating a minor revision.

This action will differentiate the current approved inspection report (e.g. version 1.0), from the new unapproved inspection report (e.g. version 1.1). When the new inspection report is approved it will become version 2.0. Through the use of minor/major revisions a document’s life-cycle is managed and controlled along with any associated business rules. Upon check-in of the inspection report the inspector will launch a pre-configured ‘review’ workflow (router).

By launching a ‘review’ router, the inspector routes the inspection report folder to the senior engineer, who will be notified by e-mail that something has arrived in his/her ABIP in-box. Upon opening the ABIP in-box he/she will:

1. be presented with the inspection report folder and any message from the inspector.
2. open the folder and be presented with the various document files for review.
3. double click on the inspection report and be prompted as to whether they want to view or edit the inspection report.
4. Upon answering the prompt, the e-form application will be launched displaying the inspection report to be reviewed.
5. At any time during the review process the senior engineer will be able to view any other documents in the folder including the photos with a universal viewer.
6. A page at the end of the inspection report will be available, with a scrollable memo field, for the senior engineer to annotate any comments.

Upon completing the review, the senior engineer will:

1. close the application.
2. check-in the inspection report with a minor revision.
3. forward the inspection report folder back to the inspector(s).

Upon receiving the reviewed inspection report folder, the inspector will:

1. review the contents for any comments by the senior engineer.
2. incorporate or resolve and edit.

If incorporated the inspection report will be checked-in again with a minor revision, thus maintaining an audit, if so desired. The inspector will then:

1. launch a pre-configured ‘approval’ workflow router.
2. route the inspection report folder to the senior engineer or supervising engineer depending on pre-defined business rules such as: *Inspection report and related documents are forward to a supervising engineer if:*

- The inspection report is for a town-owned bridge.
- The inspection report includes maintenance items.
- The inspection report reveals the bridge is in poor condition.
- The senior engineer has a backlog of work.

In any case, the senior engineer or supervising engineer will:

1. be notified by e-mail that something has arrived in his/her ABIP in-box.
2. open the ABIP in-box.
3. be presented with the inspection report folder and any message from the inspector.
4. open the folder and be presented with the various document files for approval.
5. double click on the inspection report file.
6. be prompted as to whether they want to view or edit the inspection report.
7. answer the prompt.
8. The e-form application will then be launched displaying the inspection report to be approved.

Upon reviewing the inspection report, the senior engineer or supervising engineer will:

1. approve the inspection report by electronically signing the report.
2. If the inspection report has identified maintenance items it will be routed from the senior engineer to the supervising engineer for review/approval.
3. Then, if no maintenance items were identified, when the senior engineer or supervising engineer approves the inspection report with an electronic signature, the bridge inventory information will be automatically updated.

The senior engineer or supervising engineer will:

1. check-in the inspection report with a major revision (2.0).
2. This major revision (2.0) will replace the current approved inspection report (1.0) for a specific bridge.

If the bridge's assigned inspection responsibility is going to change for the next scheduled inspection, whether it be from BS&E to consultant or consultant to BS&E, the inspection report can be routed to a system administrator who can change the security/permissions on the documents.

The effective approved inspection report can then be checked-out and a change can be made to the appropriate responsibility attribute. Once the changes are made, the inspection report can be checked-in as a major revision but be assigned a status of 'Current'. With the proper use of security and permission rules only the 'Effective' inspection reports will be available for viewing by the rest of the DOT user community that has permissions to do so. This will enable a correct bridge inspection list, by responsibility, to be produced for the next inspection cycle.

Bridge Maintenance Items Review/Approval Process ‘To-Be Environment’

See Figure 7 for the To-Be BMI Review/Approval Process. When maintenance items are included in the inspection report the senior engineer will:

1. route the maintenance items for review via a pre-configured BMI ‘review’ workflow router.
2. launch the router.
3. The router will forward the designated IR to the supervising engineer.

The supervising engineer will be notified via e-mail when the IR arrives in his/her ABIP in-box, and he/she will then:

1. open the ABIP in-box.
2. be presented with the inspection report folder and any message from the senior engineer.
3. open the folder and be presented with the various document files for review.
4. double click on the inspection report file.
5. be prompted as to whether they want to view or edit the inspection report.
6. answer the prompt.

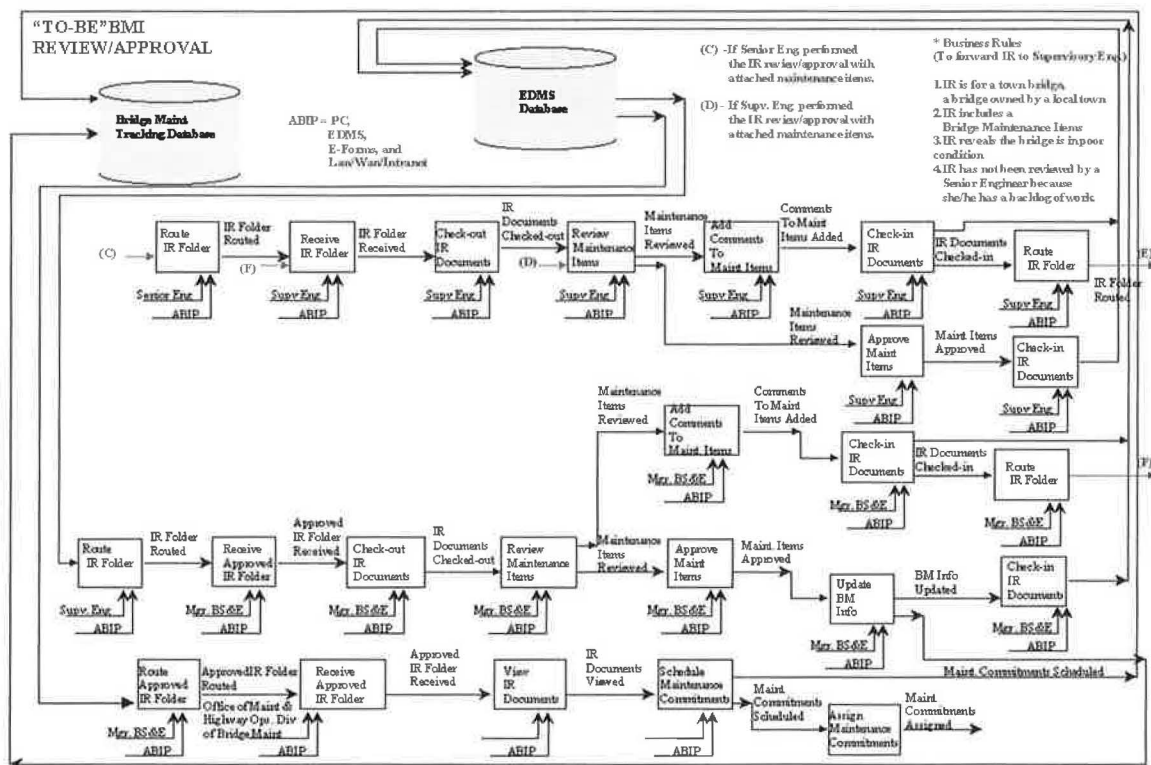


Figure 7: Bridge maintenance items review/approval process ‘to-be environment.’

The e-form application will then be launched displaying the inspection report with identified maintenance items to be reviewed. The supervising engineer will then:

1. review the maintenance items.
2. route the inspection report back to the senior engineer for clarifications, if necessary.
3. be notified by e-mail when the inspection report folder has arrived back in his or her in-box.
4. review any comments, per maintenance item, made by the supervising engineer.
5. provide an appropriate response.
6. check-in the annotated inspection report and forward it back to the supervising engineer.

The supervising engineer will then:

1. be notified via e-mail when the IR arrives in his/her ABIP in-box.
2. open the ABIP in-box.
3. be presented with the inspection report folder and any message from the senior engineer.
4. open the folder and be presented with the various document files for approval.
5. double click on the inspection report file.
6. be prompted as to whether they want to view or edit the inspection report.
7. answer the prompt.

The e-form application will then be launched displaying the inspection report with identified maintenance items and clarifications to be reviewed. The supervising engineer will then:

1. review the maintenance items and approve/disapprove the items by clicking on the appropriate radio button.
2. complete the review.
3. sign the IR with an electronic signature.
4. check-in to the ABIP the IR.
5. forward the IR folder to the BS&E manager.

The BS&E manager will:

1. be notified via e-mail when the IR arrives in his/her ABIP in-box.
2. open the ABIP in-box.
3. be presented with the inspection report folder and any message from the supervising engineer.
4. open the folder and be presented with the various document files for review.
5. double click on the inspection report file.
6. be prompted as to whether he wants to view or edit the inspection report.
7. answer the prompt.

The e-form application will then be launched displaying the inspection report with identified maintenance items to be reviewed. If the BS&E manager has any questions in

regard to the actions taken by the supervising engineer or any identified maintenance items, he or she will:

1. route the inspection report back to the supervising engineer for clarifications.
The supervising engineer will:

1. be notified by e-mail when the inspection report folder has arrived back in his or her in-box.
2. review any comments, per maintenance item, made by the BS&E manager.
3. provide an appropriate response.
4. complete an appropriate response
5. check-in the annotated inspection report.
6. forward it back to the BS&E manager.

The BS&E manager will:

1. review the maintenance items that have been approved/disapproved and clarifications provided by the supervising engineer.
2. change any approval/disapproval of items by clicking on the appropriate radio button.
3. complete the review.
4. sign the IR with an electronic signature.
5. check-in to the ABIP the IR.

When the BS&E manager electronically signs the IR, approving/disapproving the identified maintenance items, a bridge maintenance database will be automatically updated with the new approved maintenance items. The BS&E manager will then:

1. forward the IR folder with approved maintenance items to the Office of Maintenance and Highway Operations, Division of Bridge Maintenance.

Comparison Between the Two Environments

The “Current” Bridge Inspection Processes are very paper intensive. A paper intensive process adds many non-value added activities (copying, printing, filing, and mailing/ sending/delivering the hardcopy document) associated with a documents life-cycle. Table 2 illustrates the results of comparing the two process environments. The reduction of these steps or processes can be attributed to several elements:

- Appropriate use of technology
- Fundamental rethinking of existing work methods
- Focusing on the goals and objectives of BS&E.

Because of the significant reduction in non-value-added activities, the overall “To Be” Bridge Inspection Process will provide external and internal benefits to the DOT.

Table 2: Comparison of 'Current' vs. 'To Be' Process Environments

Process	# of Steps: Current	# of Steps: To Be	Non-Value Added Steps: Eliminated	% Reduction
1. Bridge Inspection & Review / Approval Process	46	20	24	56
2. Bridge Maintenance Items Review / Approval Process	17+	14+	7	18
TOTAL	63	34	31	46

⁺ Once through review/approval cycle.

Externally, the "To Be" processes will provide the means for the BS&E to provide faster delivery of bridge inspection services to the State of Conn., (e.g., the public) while improving the quality of bridge information. Internally, the DOT will benefit by having a BS&E Section that can efficiently perform more bridge inspections within a calendar year by improving the productivity of every member of the BS&E bridge inspection team.

CONCLUSION

A business enterprise like a DOT can exist when two basic conditions are met—a demand and a supply. First, there are customers (FHWA/public) who have needs (bridges inspected and maintained)—a demand. Second, the business enterprise can, and does, employ its resources to fulfill those needs—a supply. If the world were a simple place to live in, all businesses would be successful if those two conditions were met. However, we live in a very competitive world, with few skilled resources.

Realizing this, the fundamental attributes for a successful business enterprise can be characterized as follows:

- Ensuring that services conform to customers' requirements
- Providing on-time delivery with the highest possible levels of quality
- Efficient utilization of appropriate resources
- Maintaining total operating costs below approved budgets.

These characteristics are so important that many corporate, government, and public agencies have similar descriptive verbiage incorporated in their mission statements and corporate plans. Business process reengineering has become the best method to help an organization execute its corporate plan to achieve and maintain business success. ConnDOT understood the need to change the existing work methods to allow a more effective and efficient organization to emerge.

Before a DOT proceeds with the procurement or internal development of a knowledge management solution, some issues should be closely examined:

1. What cultural impact will it have on the existing organization?
2. Will work methods change?
3. Will jobs be replaced by technology?
4. To what degree will productivity be increased?

These questions are answered through the development of process flow diagrams for the 'Current' and envisioned 'To-Be' environment. It is the methodology that is the critical success factor that provides the means to develop and implement a knowledge management solution. If the objective is to adopt a knowledge management solution within a DOT, then a tested methodology along with subject matter expertise is necessary to bring about its successful implementation in an orderly and well-conceived manner.