Regaining Control: Finding the Information Needed for Effective Decision Making

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SYNOPSIS

Information technology is becoming a bottleneck in large construction projects. While computerized systems are theoretically capable of providing well-organized repositories of project information, actual practice lags far behind. The current state of the art for construction information management is generally a collection of capable, but poorly linked systems, which are often not available to all project participants.

Project management currently accepts the resulting costs of these inefficiencies because unaware of the productivity gains that could be achieved. This paper presents a vision for a unified construction information repository, and explores the technical and organizational issues faced by large projects when implementing it.

A first is step to recognize the benefits of centralizing and sharing information: it improves project efficiency and decision making. The centralized information repository is therefore a means of assisting the collaborative effort. The goal of effective inter-company collaboration clearly places the responsibility for managing project information *above* the level of the individual project participants. This realization is the key to implementing information management systems for large construction projects

Experience from the Kárahnjúkar Hydro-Electric project is presented. The paper concludes with a short outline of a more complete implementation of the authors' vision, currently under development.

1 OVERVIEW

This paper presents a vision for a unified construction information repository, explores the technical and organizational issues faced by large projects when implementing it, and offers practical suggestions based on actual experience in the field. The essence of our vision is to re-create a modern, electronic version of the traditional paper based controls formerly used on engineering projects. The material presented here builds on our previous work (see [1] and [8]).

A first step in managing project information is recognizing its goal, namely that centralizing and sharing information improves project efficiency and decision making. For efficient project execution *all* parties must be able to find all the information associated with the tasks they are assigned, which means that *all* must contribute their data and documentation so that others can find it. The centralized information repository is therefore a means of assisting the collaborative effort.

The need for effective inter-company collaboration clearly places the responsibility for managing project documentation above the level of the individual project participants. This is a departure from many attempts to implement electronic document management systems, which typically focus on implementing systems for a single entity, rather than an entire project. The change of focus is the key to implementing document management systems for large construction projects: The responsibility and authority for managing project documentation must be made early enough and at level high enough to ensure compliance across the entire project.

The authors discuss practical considerations associated with the deployment of a centralized information archive and classification system. Specific requirements for evaluating information management software and necessary to enable systems to be integrated with the project classification system are proposed. Key success factors for the methodology and tips for improving common project workflows are also provided.

Experience from Kárahnjúkar Hydro-Electric project in Iceland is presented. The paper concludes with a short outline of a more complete implementation of the authors' vision, currently under development.

2 PROBLEM DESCRIPTION

Information technology has become a bottleneck in large construction projects. Caught between the traditional filing of paper documentation and the almost 100% production of documents using computers, project staff and managers have not reaped the potential advantages of electronic documentation management. Those experienced with project work, whether in the design or construction phase, would agree that documentation problems include:

1. Multiple sets of project data are often maintained in parallel.
2. It is difficult to determine which data is checked, valid and up-to-date.
3. Important data sometimes gets misplaced, corrupted or even lost.
4. Multiple revisions of documents are found in electronic archives with no clear indication of validity.
5. Calculations using spreadsheets often lack a checking and approvals trail.
6. Verified construction history is not readily available from a single location.

Traditional engineering practices using formal workflows with prescribed checking and approval, engineering classification of data and documents, and an accessible project library, are not part of today's "Office suite mentality" encouraged by the current generation of personal computer software. Traditional approval stamps and control sheets may still be used for documents, but in practice, are very rarely used for data. Tasks are often only indirectly (and inefficiently) recorded in meting minutes (and often in parallel, in different meetings).

The predominant use of Power-Point presentations, in lieu of more formal technical reporting, typically also occurs outside of traditional project controls. The result, in some cases, is loss of rigor in project controls.

While computerized systems are theoretically capable of providing well-organized repositories of project information, actual practice lags far behind. Although revision control of drawings is usually maintained, revision control of other documents is often haphazard. Revision control with regard to data is rarely even considered.

Further, a great deal of project information (particularly email) never ends up in any documentation system. Because of the convenience and the lack of any better available means, a very large amount of project correspondence and information exchange is handled by email. In many cases email correspondence is not filed elsewhere and become very difficult to access when email folders become large, project staff leave the site or computer systems change.

The current state of the practice of construction information and document management is generally a collection of capable, but poorly linked systems, which are often not available to all project participants. Company boundaries and project responsibilities (design, supervision, contractor, owner) stifle the sharing of networked file servers. The difficulty of administering and maintaining a computer infrastructure at construction sites often limits inter-connectivity between computer systems. The typical remoteness of key players (designer, owner) from the construction site adds additional computer networking complications.

3 PROBLEM ANALYSIS

Many different types of information are used during the development of construction projects. From a project management perspective it is useful to consider a breakdown of project information into data, documents and tasks, as shown in table 1. Some overriding typical issues are also noted.

Type of Information	Examples	Typical Issues
Data	Topography Geological / Geotechnical Production Quantities	Often not subject to formal review or revision control
Documents	Design reports Design calculations Specifications Drawings Technical queries Method statements Inspection reports Photos As-built records	Difficult to find correct documents or latest revision
Tasks	Pending matters (ToDo's) Action lists Drawing lists Construction activities	Managers desire collaboration within team but want to know who does what and when

Table 1: Project Information Types

Most, if not all project information falls into these categories, although further distinction might be made for instance between schedules versus activities, between computer codes used for complex calculations versus the calculations themselves or between drawing elements (layers, blocks, references) versus the production drawings. For the scope of this paper, table 1 provides a useful overview of project information types.

3.1 Traditional Best Practices compared with Current Practice

We believe that traditional project practices (described in [5]) were very effective in controlling and distributing all types of project information. Traditional practice was also easier in that project staff were typically operating from single locations (project design office, project site). Information technology and globalization are two important change factors that have influenced project practice with regard to information management. Although these changes have resulted in many benefits such as efficiency increases in design work and construction activities, information management has not benefited to the same extent. A comparison of traditional best practice with current practice for the development of project procedures, as shown in table 2, provides some interesting observations.

Traditional Practice	Current Practice
Companies and Projects had approved procedures covering 80-90% of work, which were well documented and that were expected to be consistently used.	Globalized work teams and the lack of an accessible “library” make it often easier for project staff to start from scratch developing ad hoc procedures rather than to find or reference established procedures.
New procedures were developed and written when required using engineering methods. It was expected that the procedures developed would become standard in the future. - procedure defined (or referenced) - review - coded (e.g. calculator or simple spreadsheet) - tested & checked - approval - revision control	Procedures are developed for “one-time” use, reducing the short-term effort required, but without the realization of long-term efficiency gains. Project efficiency also suffers due to: - lack of checking - lack of documentation of procedures - data & procedures “mixed” (as in typical spreadsheet use) - lack of revision control

Table 2: Traditional Practice vs. Current Practice

As demonstrated in these observations, project managers are finding it difficult to enforce consistent administrative workflows for checking, documenting and revising procedures. As described above, they and their staffs are also finding it difficult to find relevant available project information. The common issue is that the tracking of project information needs to be improved. See table 3.

A means needs to be found which reestablishes the “gate-keeping function” of traditional project controls in the current computer-based information technology environment, but which preferably also saves times instead of increasing the effort required by the project staff. We believe that managers need to pay stricter attention to project controls, but that the controls used have to find acceptance with the project staff in order to succeed.

Traditional ‘Pen and Paper’ project controls are being forgotten
=> Workflow needs more attention. Managers need to enforce *consistent* workflow for data, documents and tasks.
=> Engineering classification of documents and tasks is still needed. In the IT (Information Technology) language, *metadata*, e.g. data that describes data, replaces stamps and control sheets.

Table 3: Critical Traditional Controls

3.2 Comparison to Other Industries

In order to understand the importance of formal controls in information management, it is illustrative to look to other fields.

NASA, America’s space agency, has had serious issues with information management [3], which were cited as one of contributing factors that led to the *Columbia* space shuttle accident in 2003. After the tragedy, the accident investigation board reported that one contributing factor was that serious technical problems were disclosed in emails and Power Point presentations. This information was not placed under any formal controls and subsequently was not available during any of the reviews that could have mandated corrective action.

In 1999, NASA lost its *Mars Climate Orbiter* due to an error caused by a failed translation between Imperial units into Metric units [9]. A major contributing factor to the mission’s failure was inadequate verification of engineering requirements and technical interfaces. In this case, it was caused by a communication failure between teams located in California and Colorado. This emphasizes the importance of having formal controls when working at a distance.

Spreadsheet errors in commerce, finance and government are serious enough that the *European Spreadsheets Risk Interests Group* [4] was formed to investigate and combat the problem. The basic problems are caused by a lack of transparency. Data is mixed with calculation methods, and it is difficult to guarantee that a spreadsheet has not been inadvertently changed. Further issues associated with managing information stored in spreadsheets are discussed in [2] and [12].

4 SOLUTIONS

The successful management of project information requires that you understand the constraints imposed by the typical project structures of the construction industry (see [10] for an overview of typical project structures). The essential insight is that construction projects are temporary alliances of many participants, who have different roles and different information requirements. Individual participants may work simultaneously on multiple projects and their individual employers often already have systems in place for data and document management. These issues complicate the deployment of a centralized information repository. This situation differs from other industries where project structures are generally simpler and are often under the direct control of a single permanent entity.

The effect on project information management is that individual project members are unlikely to be willing to invest large efforts filing and searching for project data and documentation. This is because the individuals actually working on the project typically perceive that investing effort to become proficient using project mandated systems brings less reward than learning their employer’s own systems. Stated simply, there is little incentive to use a system on a project when there is little likelihood that you will use the same system again on another project.

The individual's strategy is then to promote their own, familiar, personal computer and corporate systems, even in the face of officially mandated data and document management systems. This behavior occurs across all project participants, and the result is a proliferation of incompatible systems and an inability to find information outside one's particular domain, leading to 'information islands'.

Solutions to these problems are:

1. Select an information management system based on concepts that engineers and construction personnel already understand, and that can be used without formal training. The following should be supported:
   - Workflows for data, documents and tasks that conform to standard engineering practice
   - Filing of data, documents and tasks based on engineering classification systems

2. When the system is deployed, expend the effort required to initially fill it with a critical mass of data and documents. This is to improve user acceptance by ensuring that the system is perceived as the most likely place to find project information.

3. Mandate the use of a data and document management system at the project level:
   - Provide contractual incentives to all project partners, to ensure they use and contribute to the information archive
   - Appoint a documentation manager with sufficient resources and authority to ensure that all project information is captured

The implications of these points are discussed in the following sections.

4.1 Basic Requirements

We believe that the primary goal of information management for construction projects is to provide the technical systems and associated procedures to enable the project team to work in an *efficient* and *rigorous* manner:

Efficient – All information required to perform tasks can be quickly and accurately located
Rigorous – All information is subject to controls that ensure its correctness and validity

The basic requirements are the definitions for technical systems and procedures that enable efficient and rigorous management of project data and documentation:

1. Project information should be centralized at one location, regardless of its form.
2. The information shall be accessible to all parties, as authorized, irrespective of their global location.
3. All information should be subject to revision control and workflows
4. A single project-wide classification system should be applied to project information, regardless of its source. It should be possible to search for information using the classification system
5. The workflows, classification system and revision control should be based on concepts already understood by engineers.
6. The resulting system(s) should be simple enough to use without formal training.

Considering the motivations of the project participants (discussed in the previous section), the most important consequences resulting from these requirements are:

1. Workflows to implement the controls, which should be common across data, documents and tasks as far as practical, must be implemented. Ideally, they can be modeled on the traditional paper-based documentation controls, in a manner appropriate for computerized systems.

2. Construction staff can be expected to expend effort to learn the project's classification system. Thus, the classification system should form the basis of the filing and searching system, and be presented to users in an intuitive manner.

3. A modern information archive should be web-based and accessible using normal Internet browsers, such that no installation of additional software is required to use it. This lowers the barrier to entry for using the system as well as the required computer administration to the absolute minimum.

Further detailed requirements, beyond the scope of this work, are described in [6].

4.2 Workflow Management

Traditional paper-based project controls made use of physical stamps and signatures. After a document was produced, it was subject to formal checks and approvals before being released. The release procedures were applied to all documents and typically involved additional signoffs and official distribution to well-defined sets of recipients. Updates to documents were subject to strict revision control. The current revision of a document was *always* available and uniquely identifiable. Superseded revisions were marked as such and could also be retrieved.

Unfortunately, this practice has largely been lost during the transition to electronic document management systems. Current practice often has difficulty identifying the approval status of documents. Drawing management is typically somewhat better, because of the more immediate costs of mistakes.

The current practice results from:

1. Poor support for common construction workflows in existing document management systems

2. Use of email attachments for distributing documents, rather than registering official copies in a document management system

3. The current generation of document production tools (e.g. MS Word, Excel, Power Point, etc.) and filing systems (shared drives and Content Management Systems) encourage convenient rather than rigorous engineering procedures

Attempts have been made to overcome some of the deficiencies in software systems, by capturing document workflow, e.g. the approvals and signoffs, in electronic systems by including a ‘workflow page’ as part of a document. Unfortunately, extracting this information, say when searching, is problematic, given the wide range and proprietary nature of the file formats in use.

We propose that most construction data/document workflows be implemented directly in the information repository. Important considerations are:

1. Separate the workflow management from the actual data and document production
2. Integrate the workflow management with the engineering classification
3. Support management of lists of documents that have not yet been produced
4. Strict revision control

The most common construction workflows steps of some typical documents shown in table 4.:

The mechanics of the actual workflow steps are simple. You need to record the person responsible for the step and the date on which it was completed. A more advanced system would also record a planned completion date. Having the planned and completed dates for workflow steps provides the basic information for scheduling documentation tasks.

Some technical considerations affect the usability of workflow management:

1. It should be possible to search based on workflow status and schedule dates
2. It should be possible to have project assistants perform workflow steps on behalf of others (e.g. managers and engineers should be able to hand assistants a set of drawings that they have approved)

3. It should be possible to perform workflow operations on sets of documents (e.g. the assistants should be able to efficiently perform the approval on the set of drawings)

Example Items	**Typical Workflow Steps**
Drawings produced internally	- Design - Production - Check - Approval - Distribution
Documents produced internally	- Production - Approval - Distribution
Drawings and documents produced externally	- Receipt - Approval - Re-distribution
Inspection documentation	- Production - Approval
Correspondence sent	- Production - Approval - Distribution
Correspondence received	- Receipt

Table 4: Common Construction Workflow Steps

We also propose that tasks, including tasks related to document production and change control, be managed directly in the information repository. Besides the priority, due date, person responsible, etc. it should be possible to assign engineering classifications to tasks and to link them to documents. This allows you:

1. To see outstanding tasks associated with documents (e.g. technical queries prior to drawing revisions)
2. Use the classification system to identify sets of documents that may need updating due to a change request, and assign a task

4.3 Engineering Classification

All construction projects and personnel make use of engineering classification. Engineering classification is the basis of all drawing numbering systems and project work-breakdown structures. All projects have quality documents explaining their numbering systems and document naming conventions. While engineering classification systems differ between projects, in principal they are all the same. The intent is that information can be uniquely identified based on engineering criteria, such that *all* information association with a particular topic can be easily located.

Project participants are expected to understand and conform to these systems. In practice, engineering classification is the *de-facto* coordinate system for all project information, and should therefore form the basis of the information archive's filing and retrieval system.

A complete engineering classification system should include:

1. Work breakdown structure – project phase, engineering discipline, work type, etc.
2. Geographical structure – location code, alignment/chainage, geographical coordinates
3. Organizational structure – contract, group, supplier company, etc.
4. Cost breakdown structure – accounting and supplier codes, material codes, etc.
5. Other classifiers – data/document type, external keys, alternate assigned codes, etc.
6. Workflow information – signoffs, approvals, distribution, etc. See above section.

The classification system should be applied to *all* information in the information repository. The intent is that all data and documents are assigned as much classification information as is appropriate. Not all classifiers make sense for all documents, but better and more comprehensive classification makes retrieval much easier.

Some technical details associated with engineering classification:

1. Applying classification criteria consistently requires effort. Automatic classification can sometimes be inferred and automatically applied, based on a user's place in the project organization or the filename or the document number being filed.

2. Some information may be classified incorrectly, so provision should be made to flag incorrectly or tentatively classified data and documents for later correction or completion by project 'librarians'.

3. Tasks associated with producing and updating project information should also be assigned engineering classification. This makes it possible to find outstanding issues associated with data and documentation.

4.4 Roles and Incentives

We propose that construction projects create a documentation manager role, reporting to project management, to oversee the collection, filing and distribution of data and documents. The intent is to formally recognize the collaborative benefits of complete and well-organized documentation to the project team.

The documentation manager's main deliverable is the complete and well-organized set of documentation at project end. During the project the document manager must ensure that the information archive is kept up-to-date and that all information is well organized and easy to locate. On smaller projects this might be a part-time role. On larger projects this is a full-time position.

Projects should also appoint documentation clerks (librarians) to assist with the actual filing of information. The appointment of librarians recognizes that filing of data and documentation requires effort and training, and that it is unrealistic to expect engineers and other construction staff to expend effort filing documents, given their other full-time duties. Having librarians also reinforces the idea that the project has a single library, where all project information can be found and that help is available when information is needed.

The biggest incentive to ensure acceptance and use of the information repository is by providing the easiest access to project information. This has the following consequences:

1. The document manager must be able and willing to accept large collections of data and documents and take responsibility for organizing and filing them. Typical examples are and the delivery of sets of drawings from sub-contractors or suppliers, and creating the initial critical mass of project documents at the start of the project.

2. The document manager must constantly be on the lookout for 'information islands' and ensure that they are imported and integrated into the information archive.

3. The document manager must also take on a promotional and motivational role; identifying, encouraging and assisting *opinion leaders,* i.e. project staff who are likely to promote the use of the information archive within their teams. Note that these opinion leaders can be found at all levels in the project and are not necessarily in managerial roles.

4. The document manager must be open to suggestions for improvement from project staff. Implementing enhancements for opinion leaders is one of the best ways of improving system acceptance.

5 CASE STUDIES

This section presents two case studies from systems based on experience applying our methodology on the Kárahnjúkar Hydro-Electric project in Iceland [11]. See [7] for an additional case study.

5.1 Tunnel Inspection Reporting

At the Kárahnjúkar Hydro-Electric project in Iceland we helped implement procedures for improving the management of tunnel inspection data using the DrawMGT document management system used at the Site. The goals were:

1. Improve the efficiency and accuracy of the data collection process
2. Apply workflows – revision control and approval signoffs
3. Links to related documentation – construction drawings, inspection photos, geological reports, etc.

The key to the data organization was to use engineering classification to record the work type, alignment and chainage of all tunnel related documentation, which enabled inspectors and engineers to locate all data and documentation associated with a particular section of tunnel.

Table 5 summarizes the information management principals learned:

Typical Practice	**Improved Practice**
Ad-hoc inspection format (e.g. geological mapping, rock support classification): - No checklist: Leads to missing inspection data. - No pre-filled information (e.g. tunnel geometry). - Inconsistent reporting (e.g. geological descriptions, technical terminology, contractual terminology). - Data entered into spreadsheet or personal database. Often leads to inadequate checking after initial data entry.	Well-defined inspection forms: - Printed from documentation system, for field use. Includes checklist and pre-filled information - Field data entered into system in office using 'friendly' screens that match the printed inspection forms.
Inspection report issued and filed parallel but separate to data entry (usually as a "Word" or scanned document) - No assurance that data and report are compatible - No accessible metadata (e.g. approvals) - No searchable text	Print out inspection report to use as 'check print' - Checking - Approval and signoffs
Filing of Inspection report - Hard copy filed typically in one location, not accessible by all - Electronic copy somewhere on server, may be hard to access - Data gaps not clearly visible!	- Approved inspection data saved in data management system. - Approved inspection report saved as a document in the document management system
Data requests (e.g. measurement & payment, reporting, claims analysis, as-builts) - Typically re-compilation of data (using additional spreadsheets) - Minimal data checking after data re-compilation causing inconsistencies in reporting - No certainty that data remains unchanged over time - Inefficiencies from parallel data handling - No audit history	- Checked and approved data available in data management system. - Data can be searched (e.g. by chainage) - Standard reporting available for many cases (might include time-distance diagrams, activity charts, tunnel profiles). - Requester can specify custom reporting format, which is used to generate database report. - Any mistakes identified are corrected in database, as revision, with approvals and audit history.

Table 5: Inspection Reporting Practices

5.2 Calculation Procedure

We helped implement procedures for managing the data associated with the hydro-dynamic transient simulations and analysis for the Kárahnjúkar waterways. The task required the management of:

1. Calculation procedures – a FORTRAN program that performed numerical simulation
2. Calculation models – which represented particular waterway configurations
3. Parameter studies – for each calculation model

The primary requirements were:

1. Have an audit trail of every simulation run
2. Be able to repeat any simulation run previously
3. Automate the running of the simulation process and plotting of its result sets
4. Re-run simulations with field data to verify the initial modeling

All model and parameter studies were subject to version control, and each simulation result was flagged with a status that indicated it status and validity. We used version control for the source code of the FORTRAN code, which had to be adapted for the particular waterway conditions. We also re-ran test cases each time to simulation code was changed to determine if previous simulation results were still accurate. The entire system was web based, which allowed engineers located in Reykjavik and Zurich to collaborate on the waterway design, in spite of the distance between them.

Table 6 summarizes the information management principals applied:

Typical Practice	**Improved Practice**
A “do-it-all” software program handles data, calculation procedure and presentation.	Use is made of a document and data management system together with calculation software.
- Input data is entered directly into calculation program and is often difficult to check. - Typically no means to record data changes.	- Calculation input data is entered and stored in data management system and checked. - Revision procedures are applied if data changes.
- Calculation procedure is developed together with “live” data. Procedure and data are not clearly separated. - Checking (and approval if organization requires) are typically not tracked. - Revision history is poorly documented.	- Calculation procedure is developed (as task to allow scheduling and tracking). - Calculation procedure is reviewed (and approved if organization requires) and filed and documented on DMS. - Revision procedures are applied if calculation procedure changes.
-	- Application is made by downloading calculation procedure and downloading data in appropriate format.
- Input data used for individual result sets are not clearly identifiable.	- Individual result sets are published (e.g. in PDF format) and saved as documents, subject to version control on the DMS.

Table 6: Calculation Procedure Practices

6 CONCLUSION

The best practices learned from traditional project controls can be successfully implemented in a computerized information management system. Procurement of information management systems for the construction industry need however to address the specific constraints of construction projects. Using a centralized data and document repository, accessed by the project team via web browsers, improves project collaboration and decision making.

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