Project management information control systems

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Abstract: Construction managers rely on ready access to a large amount of project information. The entry, processing, and flow of information are important in avoiding problems, delays, and claims on construction projects. This paper describes a study of the extent and nature of project documentation and project information flows within the construction industry. The study mapped various types of project information against the documents that typically provide the information and the construction management functions that provide and access the information. From this analysis, a computer system to support the task of project information management was designed. The problem analysis, requirements specification, system design, and system implementation are described. The system allows construction managers to enter information for a wide variety of project events, cross-reference the various bodies of information, and use the information to monitor and control various aspects of a construction project. The objective of the study was not necessarily to improve upon commercially available project information and documentation tools, but to deepen and formalize our understanding of project information as an input to a larger body of work on integrated project information systems and data standards for the construction industry.

Key words: construction management, project management, document control, information flow, databases.

Résumé : Les directeurs de projets de construction comptent sur un accès rapide à un grand nombre d'informations concernant les projets. L'encodage, le traitement et le flux de l'information est important afin d'éviter des problèmes, des retards et des réclamations sur des projets de construction. Cet article décrit une étude sur l'étendue et la nature de la documentation et du flot d'informations sur les projets qui circulent au sein de l'industrie de la construction. L'étude compare divers types d'informations se rapportant aux projets avec les documents qui fournissent typiquement l'information et les fonctions de direction de projets de construction qui fournissent et accèdent à l'information. A partir de cette analyse, un système informatique a été conçu afin d'assister la tâche de gestion de l'information sur les projets. L'analyse du problème, la spécification des conditions, la conception du système et sa mise en oeuvre sont décrites. Le système permet aux directeurs de projets de construction d'encoder des informations pour un large éventail de projets, d'établir des renvois aux divers organes d'information et de les utiliser afin de surveiller et contrôler les divers aspects d'un projet de construction. L'objectif de l'étude n'était pas nécessairement d'améliorer les outils d'accès à l'information ou à la documentation, mais d'approfondir et de formaliser notre compréhension de l'information sur les projets comme une contribution à un large ensemble d'ouvrages sur les systèmes intégrés d'informations sur les projets et sur les normes pour l'industrie de la construction.

Mots clés : direction de projet de construction, gestion de projet, contrôle de documents, flot d'information, bases de données.

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Introduction

Effective control of information flow is a critical ingredient throughout the life of construction projects. Examples include the control of information to describe the required work, support decision making, analyze progress, pass on to other participants, record for future reference during claims, and support estimating on similar projects in the future (Tenah 1981, 1984, 1986). While the quantity and timing of information flows on construction projects would be difficult to administer in any industry, it is made even more difficult by several defining characteristics of the construction industry. For example, the construction industry is marked by large numbers of participating companies collaborating for relatively short project life-spans, a lack of control over the location and working conditions of construction sites, relatively low levels of management support, and fragmentation within the industry (Russell and Froese 1997).

The need has long existed for tools to streamline the job of information management for construction professionals. Although manual, paper-based information flow on construction projects still dominates, computers are increasingly becoming a central component of project information systems. Several areas in construction management, such as

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scheduling, estimating, cost control, and accounting, employ well-established computer applications. Although these tools are invaluable for carrying out the laborious calculations and data tracking for these tasks, they represent a small portion of the day-to-day construction management activities. Tools such as word processors and simple databases contribute to a much broader range of construction management tasks, but the level of their contribution is limited by their very generic nature.

This paper addresses a different class of computer applications for construction management, namely comprehensive project information systems. These systems help process and administer a wide range of project information and documentation such as drawings and specifications, correspondence, tendering documents, and progress tracking. The depth of analysis performed by these systems may be less than scheduling and estimating systems (i.e., they carry out much less detailed calculations and data processing), but they contribute to a much broader range of construction management activities. A small number of commercial software packages exist within this area of application and a number of research studies have demonstrated the potential benefits of computer-based information systems for construction projects (Barnes 1993; Chamberlain 1991; Krone 1993; Russell 1993; Tokar 1990). Claimed benefits include improvements in the speed of data processing and data retrieval, data accuracy, project management efficiency, decision-making support, document reduction, responsibility tracking, and historical document tracking.

This paper presents results from a research project that attempted to draw from past work in this area to analyze information flows in construction and to produce a series of matrices that describe information users and sources on construction projects. The paper then describes the analysis and design of a prototype project information management system. The problem analysis, requirements specification, system design, and implementation of the system are described. The system allows construction managers to enter information for a wide variety of project events, cross-reference the various bodies of information, and use them to monitor and control various aspects of a construction project.

The primary goal of both the information analysis phase and the system analysis and design phase is not to necessarily improve upon existing commercially available tools, nor to produce a system that is entirely viable as is for use on actual projects. Rather, the primary goal is to contribute an understanding of construction information and documentation that is more detailed and structured than any we have found in current research or practice. Although it is beyond the scope of this paper, this work forms an important ingredient to a larger research program aimed at producing advanced integrated systems for project management and data standards for information exchange within the construction industry (Froese at al. 1997).

Related work on project information and information systems

This section provides a brief overview of several studies reported in the literature relating to information systems for construction projects. A number of commercial software packages that relate to this topic are also listed. The sources outlined here provide the basis of the analysis of project information flows and the system development presented in the following sections.

The construction industry is information intensive. It needs accurate, reliable, and timely information regarding legal requirements, building codes and standards, manufacturer's specifications, site-specific data, past projects, etc. Several issues concerning information in the construction industry have been identified in the literature. For a contractor, the management of project information begins the day the decision is made to bid on a contract and continues well after the close-out phase (Kangari 1995). A great many types of documents are used during the construction process (Ganeshan et al. 1994). Keeping track of information flow on a construction job site is a vital task that has a direct bearing on the timely completion of a building project (Rasdorf and Herbert 1988) and on issues such as disputes (Kangari 1995).

Russell (1993) describes a computerized approach for collecting and processing site information which builds on the traditional superintendent's daily site report. Krone (1993) discusses the benefits of managing construction change orders with computers over manual methods. The purpose of a computer-based information system for engineers is to integrate the collection, processing, and transmission of information so that engineering professionals can gain more systematic insight into the operations and functions they are managing (Lock 1993). The primary function of the computerized information system is to improve the efficiency of the project manager in retrieving project information from existing records (Tokar 1990). Virtually all medium- and large-size construction firms have computer-based organization of cost accounts and other data. With advancements in computer technologies, particularly in database management systems (DBMS), it is cost-effective to develop a computerized database for even small projects and organizations.

A database can be seen as an attempt to overcome some of the limitations imposed by conventional filing systems, such as uncontrolled redundancy, inconsistency, difficult data sharing, and modification inflexibility. Mazerolle and Alkass (1993) propose a DBMS in a project control process to store information on each delay when it occurs. Hiroshi and Nobuoh (1993) describe a filing system of construction pictures and its integration with a database.

Bowler (1994) points out the importance of relational database management programs (RDBMS) in the engineering office and discusses the use of databases for technical, project management, business development, and administrative applications. Hamilton (1991) states that using a relational database improves record management processes such as tracking the progress and location of shop drawings within a firm, listing present and past projects, maintaining correspondence, calculations, telephone records, and memoranda.

Several commercial and research software systems exist that contribute in varying degrees to project information management. For example, one document and contract control software for engineering and construction, Expedition (Primavera Systems, Inc.), was developed specifically for the construction industry. Expedition can help to manage tasks such as reviewing a submittal, making notes from a telephone conversation, or double-checking approvals on a change order. It helps to file, track, or retrieve a wide range of contract information. Other related commercial packages include Project Axis (Frontrunner), Job Center (Quickpen International), and Prolog Manager (Meridian Project Systems).

Resident management system (RMS) is a DBMS developed by the U.S. Army Corps of Engineers to support the three-phase inspection process used by the Corps of Engineers to administer construction projects (Ganeshan et al. 1994). In this system, work is divided into work activities, and the contract requirements for each activity are maintained with that activity. It also helps to write and track modifications, manage contract finances, process progress payments, and complete contract correspondence.

MULTROL, a multimedia project control and documentation system, was developed by Liu et al. (1994). The retrieval of project information is assisted by a graphical user interface and user-definable queries to support various needs of construction management. This system allows the storage and retrieval of project information in the format of text, image, video, and sound.

A framework for system analysis and development

As illustrated by the preceding discussion, numerous studies have focused on information flow throughout construction projects, and a number of computer programs have been developed to help support this area. However, we have not found a thoroughly comprehensive treatment of the documents and information flows within construction projects, particularly as they relate to computer support tools. Furthermore, we are interested in examining how issues of project information systems fit within a larger context of integrated project management systems and standard data models for representing and exchanging all forms of project information among all project participants (Russell and Froese 1997; Froese et al. 1996, 1997). The research reported in this paper took a step towards this objective by attempting to produce an extensive inventory of the types of documents used on construction projects. This was subsequently analyzed to develop a clearer overall understanding of the functionality and information flows involved. This work culminated in the design and implementation of a prototype Project Management Information Control System (PMICS). While this system did address some areas not covered by other existing systems mentioned above, a major objective of the system was to serve as a focal point for collecting and analyzing data about project information flows for integrated computer systems rather than create a new class of software application.

To meet the goals of this research, a formal development methodology was adopted. Several researchers have addressed different aspects of development methodologies for information systems (Sadri and Kangari 1993; Sanvido and Paulson 1992; Couzen et al. 1993). Scarponcini et al. (1989) proposes some common conditions of methodologies for designing databases for the construction industry by emphasizing that "information follows function." The functions executed by construction personnel dictate the information that these personnel need and provide. The functions must be understood before the information can be identified and efficiently modeled.

On the basis of these researchers' recommendations, a development framework was established (see Fig. 1). The model includes four phases: domain analysis and document identification, requirements formulation, system design, and implementation. Each phase includes different steps and procedures, and identifies its final product. The following sections explain the framework for the system development, describe the procedures adopted for each element of the framework, and comment on the results.

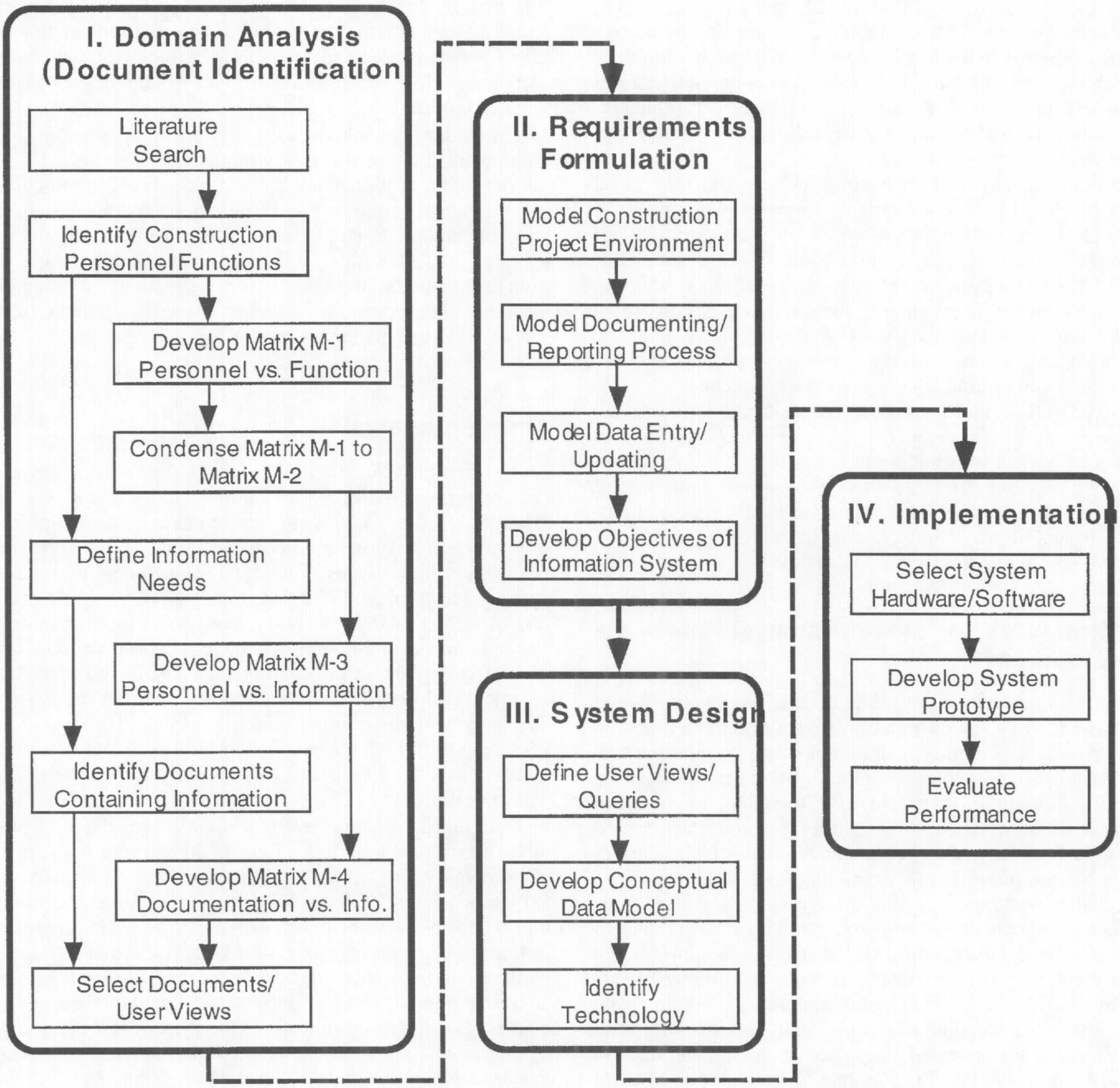
Domain analysis

The first phase of the PMICS development effort involved an analysis of the domain of project information systems. This included a study of the environment, users of information and their information needs, and sources of information. To address these issues, some type of analytical tool was required. This tool could be descriptive, illustrative, or graphical. A matrix model is useful when two or more entities are related, and several researchers have proposed various forms of matrix models for information analysis, including a "management recipients – summary reports" matrix (Tenah 1984), a "document–distribution" matrix (Lock 1993), a "project–responsibility" matrix (Peters 1984), a "data–process" matrix (Benyon 1990), and a "personnel–functional" matrix (Barton 1985).

Drawing upon some of these approaches, the first phase of the current research focused on identifying construction documents which contain information that is used by construction personnel for solving problems, pursuing claims, providing instructions to site personnel, etc. This represents a bottom-up approach to systems analysis, that is, starting with a study of the specific data and processes in the as-found domain and working towards a comprehensive logical or conceptual framework of the system and the domain. A matrix approach was adopted to determine the information needs and the documents that contain them. A set of four matrices was developed for this purpose. The following steps, as shown in Fig. 1, provided the necessary information for the next phase.

The first step of this phase of the research involved a thorough literature search of several fields relating to construction projects, including documentation, organization, personnel roles, claims, risks, the use of multimedia data, integrated information management, economics, construction management, and civil engineering computing. This literature search aided in the understanding of documents and their purposes, construction personnel roles and responsibilities, advances in integrated information technology, etc. It also led to the production of a framework for construction documentation, particularly a breakdown of documents, a breakdown of participants, a document–participant matrix, and common data items across documents.

Fig. 1. Proposed framework for the system development.



The second step was to identify construction personnel functions. This step involved identifying various construction personnel along with their roles and functions. Based on the literature review, a first matrix, M-1 (Appendix, Fig. A1), of personnel versus functions was developed wherein each component of the functions of construction site personnel was defined. Matrix M-1 includes all the generic functions of construction personnel during the construction phase of a project, including general management, accounting, financing, personnel management, engineering, estimating, planning, project management, construction management, site management, procurement, and safety. Matrix M-1 was then condensed to produce a construction personnel versus functions matrix M-2. Matrix M-2 (Appendix, Fig. A2) focuses only on the project and site management functions.

The third step was to define the information needs of construction personnel. This involved identifying the type and attributes of information needs based on the functional requirements of each construction personnel. This analysis is presented in matrix M-3 (Appendix, Fig. A3), which was derived by relating the construction personnel defined in matrix M-2 with the information they require in order to carry out their functions.

A fourth step involved identifying the documents that contain the information outlined in matrix M-3. This is described in matrix M-4 (Appendix, Fig. A4), which shows documents versus information.

Based on matrix M-4, several central documents or user views were identified. A selection of 13 of the most frequently used views was considered for the system development. The selected views are a bill of quantities, bid summary sheet, change orders log, correspondence log, daily site reports, defective work notices log, materials storage log, monthly progress reports, site photographs log, requests for information (RFI) log, shop drawings log, spare parts log, and punch list log. Each of these views is discussed in the System design section later in this paper.

Requirements formulation

Working from the above analysis of the project information domain, the next phase was formulating the requirements for the PMICS. This phase defined the purpose of the database, the scope of information to be contained in it, and the desired functionality. The steps for this phase are shown in Fig. 1 and discussed in the following sections.

The construction project environment

The construction project environment is dynamic, complex, and information-rich. Construction projects progress through various life-cycle stages, such as tender, award of contract, preconstruction, construction, and commissioning. After a construction contract has been executed, all the bids from suppliers and subcontractors are reviewed so that contracts can be awarded and other commitments firmed up to start the flow of labor and materials to the job site. During these stages, the project manager needs information to make important decisions. The bulk of information associated with construction projects requires a formal organization to maintain control over the information. Effectively managing this bulk of information to ensure its availability and accuracy is an important managerial task.

After analyzing the construction documents and establishing information needs, it is necessary to assess the construction environment to specify the context and requirements for an information system. This is required to establish a scope for the database and the business areas or functions to be addressed.

The typical user envisioned for the PMICS is a small- or medium-sized construction company (the system could also apply to larger companies, though they may rely on larger scale enterprise systems rather than stand-alone desktop systems). This company works as a general contractor on most of its projects and employs a number of trade subcontractors. The company employs a number of managers to oversee projects. Depending on their specific functions and responsibilities, the managers prepare and receive numerous periodic reports, including progress reports, daily reports, cost reports, and project control reports. An organizational chart for such a company was used to depict the various users and their interrelationships for the PMICS.

The project participants that typically collaborate in the construction process include the project management team, the contractor's home office, the owner, architects and engineers (A–E), subcontractors, suppliers, and equipment rental companies. This aspect of the construction project environment was modeled through a participants–information flow diagram.

For the most part, the typical user's company is already carrying out many of the tasks or application areas addressed by the PMICS. The project management staff normally prepare all the reports and tracking logs. Information is gathered by the project's office engineer and entered into various tracking logs, either on paper or in the computer. The project manager receives information on printed forms from various sections or sites, and there is significant duplication. The appearance of reports resulting from the PMICS may remain largely the same as that of the existing ones, but the efficiency of maintaining them, the consistency of the information, and the ability to distribute the information would all be greatly enhanced.

Sources and uses of construction information

The information contained in a PMICS would originate from, and be disseminated to, a variety of sources. Although the matrices described previously give some indication of these information flows, the sources and uses of some of the main bodies of information were analyzed in more detail. Some of the information, such as a standardized coding scheme for projects' work breakdown structures (WBS, a list or chart of work items), is not specific to one particular project. Such information would be developed over time within a construction company and would reside within the PMICS system with only infrequent updating. Some project-specific information such as a general description of a project and its participants would be obtained at the beginning of the construction phase and would remain static during the entire construction project. Other information such as correspondence logs or daily site reports would require periodic or even daily updating throughout the life of the project. Default values can be included to reduce some of the data entry requirements (Russell 1993). The information gathered in a system would be distributed to participants throughout the project, with the recipients and regularity dependent upon the content of the specific reports. A more detailed breakdown of the various information sources is provided in Shahid (1996).

The objectives of the information system

The proposed PMICS is intended to be a user-friendly application that is easy to access by the different project team members. A form-oriented user interface is desired. The main objectives and the scope of the PMICS are as follows:

- To increase the efficiency and effectiveness of the project information management function.
- To enable more project reports to be made available more frequently with less effort.
- To eliminate redundancy within various project information sources and to standardize the format used for the various reports.
- To reduce the amount of time spent recording, preparing, and posting reports.
- To improve the tracking and control of the project and activities status.

System design

The third phase of the research involved transforming the requirements identified in the two previous phases into a system specification and designing a user interface. All the information or data required as output was reviewed and defined in detail before starting conceptual data modeling. All the main entities to be tracked in the proposed application were listed, including the characteristics of each entity and the required system output. This process led to the formation of a series of selected user views.

A user view is defined as a subset of data required by a particular user to make a decision or carry out some action (McFadden and Hoffer 1988). User views were identified by reviewing tasks that are performed or decisions that are made by users and by reviewing the data required for these tasks and decisions. The important sources of information for user views include existing reports, tracking logs, files, documents, and displays (these have been discussed by several researchers such as Tidwell 1992, Fisk 1993, O'Brien 1990, Levy 1994, and Callahan and Bramble 1983). Each user view yielded a set of data items that are of interest and are logically related to each other. Entity–relationship (E–R) diagrams were used to model the relationships between these data items. These models helped identify entities of interest, their attributes, and their relationships. From these, a data dictionary for the system was created to capture the full definitions, characteristics, and attributes of all data entities.

The models underlying the individual user views were combined into an overall conceptual model. This model depicts a few central entities, such as projects, work items, and participants, and identifies the transactions that must be tracked throughout the life of the project. The user views of the PMICS and the combined conceptual model are briefly described in the following sections.

View 1: bill of quantities

A bill of quantities (BoQ) is a schedule that gives brief descriptions and quantities of all the items of work involved. The quantities of work are computed from contract drawings and associated documents according to standard measurement methods. The contractor enters a unit rate against each item of work and the extended totals are added to give the tender total. The contractor requires a BoQ to build up his tender for both lump-sum and unit-price contracts (prepared by the contractor or provided by the owner, respectively). The information from a BoQ is useful in quoting for a job, estimating the cost of developing a new site, subcontracting out, producing a site budget and cash-flow forecast, preparing periodic progress payment requests, providing information to enable accurate cost control during the site construction, etc.

This view provides bill of quantities information to the construction manager, chief estimator, procurement manager, project manager, project engineer, planning and scheduling engineer, cost engineer, estimator, field engineer, superintendent, and foremen. Typical queries for this view involve finding the quantity, cost, and budget of an item, and providing total project cost summaries.

View 2: bid summary sheet

Several bidders bid for various work packages or trades on a construction project. Before beginning any contract negotiation, all the bid information must be organized and collated. A bid summary sheet is useful as a collection point for information about bids submitted, bids requested, and bids received on each of the trades of a project. Quotes submitted by bidders can be recorded and stored for later review. The purpose of this view is to provide a means of comparing one quotation with another to ensure uniformity or to highlight differences.

This view provides bidding information to the project manager, procurement manager, and estimator. The following queries are typical for this view: find quotations and bids from subcontractors and suppliers for different trades; compare quotations with budget; provide a bidder ranking list or find the most competitive bidders to negotiate with; list the selected subcontractors and suppliers; and find the start and completion dates for a trade in order to call the selected subcontractor to start the work.

View 3: change-orders log

A change order is a written agreement to modify, add to, or otherwise alter the work from the approved contract plans and specifications. Although either party may initiate the change order, it is usually prepared by the owner and submitted to the contractor, who signs it and returns it to the owner for acceptance. Most construction projects go through contract modifications or changes during their construction phases, and these changes can be the primary causes of disputes and claims because they modify the original contracts and record changes in the contract price and the project schedule. Hence, it is necessary to monitor and track the change orders and their effect on the contract cost and completion time through the use of a change-orders log. This log is also invaluable for locating and retrieving change-order documents from files.

This view provides change-order information to the project manager, project engineer, construction manger, procurement manager, planning and scheduling engineer, estimator, accountant, superintendent, and foremen. The information describes the current status of a change order and its details, including description, approved change-order amount, time impact, revised contract price, and revised completion date. Typical queries for this view include find the work items and trade subcontractors affected by a change order, find the contract time impact in days and the revised completion date resulting from a change order, find the change-order amount and revised contract price, and find the status of a change order and the responsible subcontractor.

View 4: correspondence log

Construction projects produce a large amount of correspondence, a principal method of communication between site and external organizations such as owner, engineer, subcontractors, and suppliers. All important incoming and outgoing correspondence (such as letters, memorandums, interoffice communications, reports, and invoices) must be recorded in a correspondence log for future retrieval. This log is an invaluable means of locating correspondence in case it is needed for substantiation or negotiation.

This view provides information to construction managers relating to correspondence such as letters between project participants, change-order packages, submittal records, as-built drawings, specification interpretations, records of negotiations, minutes of meeting, memoranda, interoffice communications, reports, and invoices. The following queries are typical for this view: find a specific item of correspondence; find the contents of a piece of correspondence; find the originator or receiver name; find the original date and receiving date; and locate filed correspondence or submittals.

View 5: daily site events–reports (daily report)

Construction projects generally maintain daily site reports as a principal method of recording project activity and conveying information on site matters to the home office, the owner, and other parties. A daily report traditionally records the number of equipment working; names of the subcontractors working; amount of labor present for both the general contractor and the subcontractors; description of the work accomplished during the day; weather conditions; visitors to the site; problems encountered during the day; additional workers, equipment, or materials necessary for near-future work; and requests to the home office. This document becomes a part of the permanent file and is one of the most useful sources of information in the event of a dispute.

This view provides project managers with the daily site information reported by the field engineer or superintendent. Typical queries include find the details of subcontractors' force account (number of people working on the jobsite); find the details of work progress and equipment; find the details of weather conditions; find the names of visitors and the purpose of their visit; and prepare and print the daily report.

View 6: defective-work notices log

A defective-work notification is a written notice of deficiency and a formal demand for corrective action by a contractor. Defective work refers to work that does not meet the contract requirements. The engineer or owner's representative may reject work on the basis of noncomplying work, material, or tests of material. A defective-work notices log is helpful in tracking down the defective-work notices received and the subsequent related actions taken for correction. As any noncomplying work is subject to removal and reconstruction, corrective action, or acceptance by the owner upon consideration of a price discount, this log is very useful in tracking down rejected work and the nature of the rejection, corrective actions needed, and the estimated value.

This view provides information about defective-work notices to the project manager, project engineer, field engineer, and superintendent. The information relates to the notices issued by the architect–engineer of a project and the corrective actions needed. The following queries are typical for this view: find details of noncompliance notices; and find a list of outstanding rejected work items and their status for field inspection.

View 7: materials storage log

This view describes materials delivered to the site but not yet incorporated into the facility. Information about the availability of materials is always helpful in order for construction to proceed smoothly. Some contracts even allow for partial or full payment of stored materials. When costly items that require long fabrication lead times are delivered to the site, partial payment is often requested while they are stored on site. A materials storage log is useful in tracking stored materials, their location, and value.

This view provides the project manager, project engineer, purchasing agent, estimator, and superintendent with information about materials delivered but not yet incorporated into the work. Typical queries include find the status of on-site materials so that new materials can be procured as necessary, and find the value of materials stored and installed.

View 8: monthly progress reports

To claim progress payments, a contractor is required to submit a monthly progress report showing the estimated quantity of work done up to the end of each month. This is important, since it provides a cash flow to progress through the job smoothly. A monthly progress report is a means of itemizing work completed to date and extending the amount during the current pay period. This report includes all the items on the BoQ and additional columns to show the current month's progress (quantity or percentage, and earnings), and progress to date. This view also provides the total monthly value of work done for a particular trade for an interim payment to subcontractors.

This view provides monthly and up to date progress information to the construction manager, project manager, project engineer, estimator, planning and scheduling engineer, and field engineer. The following are typical queries for this view: find the progress of work; find the work remaining for updating the project schedule; and determine monthly progress.

View 9: site photographs log

Photographs of job progress or construction details are a valuable part of the project documentation and are sometimes required by the project specifications. This leads to a considerable amount of work in photograph and negative handling alone. Even if it is not a project requirement, many contractors take job photographs for a variety of reasons such as recording unusual project conditions, recording a complex construction process to show compliance with the contract documents, recording the condition of materials and environments, or helping substantiate a change-order request. The type of photograph is related to its purpose: progress photographs, public-relation photographs, time-lapse photographs, claims-exhibit photographs, etc. A site photographs log is useful for tracking photographs by roll number, negative number, facility or area, date, keywords, etc. The log also establishes the date and sequence of photographs intended for claims exhibits.

This view provides a project's photographs information to the project manager, project engineer, planning and scheduling engineer, and field engineer.

View 10: requests for information (RFI) log

During the bidding and construction phases, a number of questions arise regarding interpretation of the plans and specifications. These field questions are often termed requests for information (RFI) or requests for clarification (RFC). In most construction contracts, the engineers are obliged to provide answers to the questions in a reasonable amount of time. Late clarification is sometimes a basis for claims. Hence a system is required for filing, locating, and retrieving both questions and answers throughout the life of a project. A RFI log is a means of logging and tracking field clarification questions, critical items, and their dates. This log is used when subcontractors raise questions that require answers from the general contractor or design consultants, or when the general contractor needs to obtain information or clarification from a subcontractor or owner–architect–engineer.

This view enables the project manager, chief engineer, and project engineer to control information about RFIs or clarification from different project participants. The following queries are typical examples for this view: retrieve a particular RFI; find details of a particular RFI; find the total response time; list the outstanding RFIs; and find the contact numbers of the engineer and subcontractor.

View 11: shop drawings log

Submittals arise on construction projects when contractors and subcontractors submit shop drawings, samples, certificates, test results, etc. for review by the owner or engineer. These submittals contain detailed information concerning relationships, quantities, construction methods, locations, sizes, and other information about equipment or materials to be incorporated into the construction project. The project specifications establish the procedures for handling shop drawing and any other submissions, generally requiring the engineer to review, comment on, and return shop-drawing submittals to the contractor within a certain time frame. Shop drawings that are returned late can form the basis for a claim for time extension or can have other impacts on the project. It is also important to note when a particular submittal is due from the subcontractors and suppliers so that they can be reminded of this date. A shop drawing log is a documentation of all shop-drawing transmittals received from the subcontractors or sent to the engineer, and a record of the action taken in each case. It is a means of logging, tracking, and following up on submitted shop drawings. Not only does such a tracking log allow a project manager to keep track of which drawings have been received, but it also shows where the drawings have been sent and how long they have been there.

This view provides shop-drawing and other submittal information to the project manager, project engineer, purchasing agent, and superintendent. The information relates to the status of submittals from a subcontractor or supplier for review by the architect–engineer. Typical queries include find shop drawings due for submission, find the details of a particular shop drawing, find the status of a submittal and its approval, and find the time lapse for a shop-drawing review.

View 12: spare parts log

Some construction contracts require the installation of different types of equipment along with a large inventory of spare parts to be handed over to the owner at the end of the contract. A spare parts log is a means of tracking spare parts that have or have not been delivered to the owner.

This view provides spare-parts information to the project manager, procurement manager, purchasing agent, and superintendent. The information lists various spare parts to be delivered to the owner and their status. Queries for this view include find the status of spare-parts delivery, and find the list of spare parts to prepare a purchase order.

View 13: punch list log

A punch list is a list of items, usually minor, prepared by the owner or engineer which must be completed by the contractor before a project is finally accepted. From a contractor's standpoint, the punch list is the final doorway to project completion and acceptance. To ensure prompt completion of this critical close-out requirement, a definitive method of recording, tracking, and reporting punch list items is a necessity of the project. A punch list log is a useful means of recording, tracking, and reporting punch list items. It contains the date each punch list item originated, an accurate description of the work to be done, the person generating the item, an estimated dollar value of the work, the date each punch list item was rechecked, and the person rechecking the item.

This view provides punch list information to the project manager, project engineer, field engineer, and superintendent. A typical query would be to find the status and details of remaining work items and the name of the responsible subcontractors.

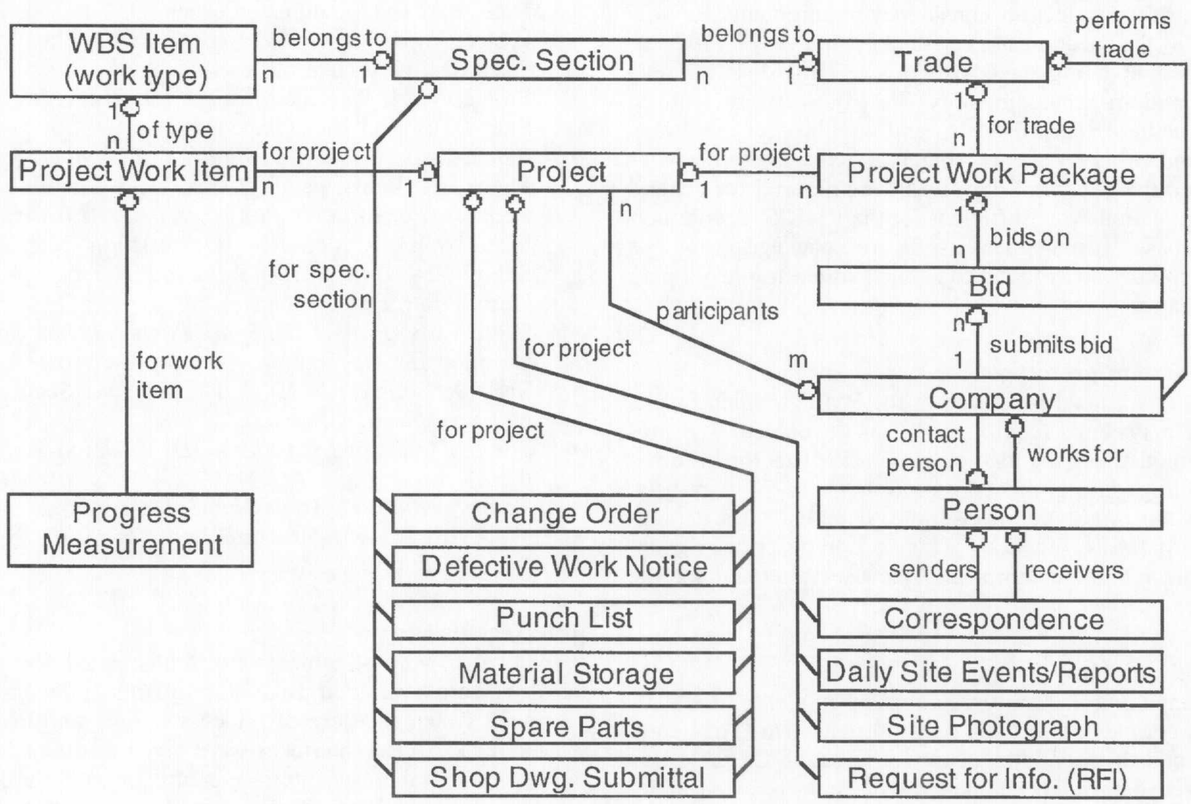
Development of an integrated conceptual data model

The data views described above were combined and distilled into a single overall conceptual model for project information content and information flows. This section describes some of the central concepts around which the conceptual model was based. A simplified illustration of this model is shown in Fig. 2.

Entities are defined to allow the classification of construction work at various levels of detail. One of the concepts used to classify work is a specification. A specification is a part of the contract documents containing technical descriptions of material, equipment, construction systems, standards, and workmanship. However, the specifications also define a classification scheme for categorizing all of the work carried out on the project, generally according to a traditional standardized breakdown scheme. Classification schemes such as CSI Masterformat are widely accepted, though not universally, in the construction industry (Froese 1993; Ganeshan et al. 1994). CSI Masterformat also provides a framework for organizing all construction documents. For the proposed PMICS, many of the files and documents are classified according to a listing of specification sections which are based on CSI Masterformat sections.

Specification sections, however, are not precise enough to use for differentiating all of the individual items in an estimate, for example (Stewart and Stewart 1986). Thus the specification sections are related to a more detailed work breakdown structure (WBS) classification scheme adopted from the American Society of Professional Estimators (ASPE) classification hierarchy, which is parallel to the CSI

Fig. 2. A simplified conceptual data model for a project information control system. (m and n represent cardinality greater than 1.)



Masterformat classification hierarchy. A work item is defined as a portion of work that can be observed, identified, and separated for purposes of estimating, cost accounting, and management (Collier 1994). The WBS items defined in the PMICS model identify categories of work items.

Whereas WBS items are more detailed than specification sections, a list of trades is more general. A trade is a division of work covering all activities related to the same field, e.g., plumbing, HVAC, or electrical. The PMICS adopts the assumption that all specification sections categories will fall within the domain of a single trade, but each trade may involve work from numerous specification sections (this seems to be generally true, though it may oversimplify the actual case). Since WBS items are related to specification sections, which in turn are related to trades, any WBS item can be associated with a specific trade.

The PMICS model includes a general representation for companies and people. Companies that are subcontractors or suppliers can be related to one or more trade areas. Thus, for any WBS item, specification section, or trade category, all related subcontractors or suppliers can be identified. Other companies such as general contractors or designers can also be represented. Individuals can be represented and are associated with the companies they work for. The employees of the user's company can also be recorded in this way. Each company can have one or more contact people defined.

A construction company can have multiple projects running or completed. All of the participating companies involved in a project can be recorded. A database of projects can therefore be used to get information about past projects of similar type; list the architects, engineers, or project managers on previous projects; or identify past projects within a specified location, for example.

For estimating and project control purposes, a breakdown of project work items involved in a job is defined for each project. The work items are related to the WBS items classifications. At a broader level of detail, the work packages that are put out to tender are also defined. Work packages are associated with individual trades and with the bids submitted from individual companies for the work.

Various project information items are then defined. Some of these can be related to specific project work items, such as progress measurements and shop drawings. Other information can be categorized by specification section, including change orders, defective-work notices, punch lists, material storage information, and spare-part records. Still other information is related only to the project in general, including correspondence, daily site activity records, site photographs, and requests for information. For each of these information items, logs of information transactions can be maintained. Although these are not shown in Fig. 2, it is these logs of information items, along with a BoQ that summarizes all project work items and a bid summary sheet that lists all bids, which define the 13 user views presented previously.

Implementation

The final phase of the system development maps the conceptual model to a physical database structure, following the design specifications and user requirements identified in previous phases. The following steps, as shown in Fig. 1, were carried out in this phase.

Select system hardware and software

The hardware selection considered requirements for factors such as the speed of the personal computer (PC) for processing and updating data, size of the hard disk for data storage, random access memory (RAM), software requirements (database, spreadsheets, and graphics capabilities), and expandability of the computer system. Overall, it was determined that a typical desktop PC configured for general office applications was sufficient for the PMICS. A commercial database management software package such as Microsoft Access was found to be well suited for developing the application.

Develop system prototype

A fully operational prototype of the PMICS which fulfills most of the system's requirements was developed. The prototype demonstrates the idea of using a PMICS for information handling during the construction phase of a project. Although the prototype was simple, it realistically demonstrated all database functions. This section describes the design of the relational tables and the user interface for the prototype.

Relational database design

After finalizing the entity–relationship model, all the entities were normalized to their third normal form. They were then mapped to the relational model, creating 25 tables, as summarized below. The name of each table is listed along with some of the typical data fields for each table in parentheses (the primary key fields for each table are in italcs). As the purpose of the database is to create queries, forms, and reports that successfully retrieve data from more than one table, a number of default relationships were defined to relate the information in the various tables.

- Bids (*Project ID*, *Trade ID*, *Bidder ID*, Bid Package Sent, Bid Received, Bid Amount, ...)
- Change Orders (*Project ID*, *Contract Modification Request Number*, Specs ID, Initiation Date, Current Status, Description, ...)
- Companies (*Company ID*, Company Name, Company Type, Contact Person, Address, ...)
- Correspondence (*Project ID*, *Correspondence ID*, From Person ID, To Person ID, Date, ...)
- Daily Events (*Project ID*, *Date*, Daily Report Number, Prepared by ID, ...)
- Daily Weather (*Project ID*, *Date*, Temperature, Cloud Conditions, ...)
- Defective Work (*Project ID*, *Defective Work Number*, Specs ID, Notice Date, Description, Date Received, ...)
- Materials Stored (*Project ID*, *Material ID*, Specs ID, Location ID, Item Description, Original Value, ...)
- Monthly Progress (*Project ID*, *Progress Statement Number*, WBS ID, Date, This-Period Quantity, To-Date Quantity)
- Participant Types (*Type ID*, Participant Type)
- People (*People ID*, Last Name, First Name, Company ID, Title, Address, Phone, ...)
- Photographs (*Project ID*, *Photo Number*, Photo Type ID, Roll Number, Negative Number, Date Taken, ...)
- Photo Types (*Photo Type ID*, Photo Type)
- Projects (*Project ID*, Project Name, Project Type, Start Date, End Date, Address, Owner ID, Engineer ID, ...)
- Project Work Item(*Project ID*, *WBS ID*, Quantity, Unit Price, Delivery Date, ...)
- Project Work Package (*Project ID*, *Trade ID*, Budget, Start Date, End Date, Subcontractor ID, ...)
- Punch Lists (*Project ID*, *Punch List Number*, Specs ID, Punch List Items, Facility/Area, Date Identified, ...)
- Requests For Information (*Project ID*, *RFI Number*, Initiated by ID, Response by ID, Initiation Date, ...)
- Submittals (*Project ID*, *Submittal Number*, WBS ID, Description, Disposition, ...)
- Spare Parts (*Project ID*, *Spare Parts Number*, Specs ID, Location ID, Description, Quantity Required, ...)
- Spec Sections (*Spec ID*, Trade ID, Spec Section Number, Spec Section Name, ...)
- Storage Locations (*Location ID*, Location Name, Address)
- Trades (*Trade ID*, Trade Name, Description)
- Work Breakdown Structure Item (*WBS ID*, Spec ID, Item Description, Unit, ...)

Interface design

After the database tables were implemented, the user interfaces were developed. Like other relational database management systems, Microsoft Access allows multiple views on the data. All the interfaces were given a similar look and feel. Although the user interface centred around the 13 main user views defined previously, various user interface formats and subforms were provided, leading to a total of 31 queries developed to support 57 various user interface forms and 14 report formats for information distribution. Finally, several macros (processing routines) were defined to help automate some of the steps involved in working with the system.

Performance evaluation

The general performance of the prototype system was evaluated against several typical test cases. Sample data representative of actual use were entered into the system and numerous typical queries, forms, and reports were generated. The prototype was found to meet the objectives of the proposed system. The prototype was not tested on an actual construction project.

Conclusions

To summarize the research reported in this paper, a study was undertaken to evaluate information and information flows on a construction project, particularly as they relate to computational tools for helping to manage project information. The project included an extensive literature search and survey of information management for construction projects. Based on this study, several matrices for evaluating project personnel, their information needs, project documents, and the information content of various documents were developed, along with global data models for documents in the construction industry. A system design methodology, which could be applied to information system development within most organizations, was developed and used to create a prototype Project Management Information Control System (PMICS).

PMICS supports project managers' information control requirements through several key features. These include the provision of a project information storage and retrieval database to facilitate the task of job site information control, an expanded means of problem identification and tracking which includes transaction management, the ability to generate a wide variety of periodical reports (e.g., daily site report, monthly progress report, outstanding shop-drawing report), and the ability to support claims analysis (e.g., by tracking and reporting cost and time impacts of change-order approval and shop-drawing approval).

The database system presented in this paper is general enough that it can be used for the control of project management information for any construction project. It is anticipated that the use of database technology in project management applications will continue to become as routine, and as important, as the use of word processing and spreadsheets in construction offices. The increased understanding of the information requirements, content, structure, and flows on construction projects developed from this study provides an important input to ongoing efforts to improve computational tools for the construction industry and to facilitate widespread integration through industry data standards.

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Appendix. Information analysis matrices

Fig. A1. Personnel vs. functions matrix M-1.

PERSONNEL vs. FUNCTIONS MATRIX (M-1)

Legends:
A= advisory/assist E= execution
C= control responsibility H= handle
D= data provisions
R= review & analyze

MANAGEMENT LEVEL:	Top					Construction					Project								Functional					
Function/Activity (Responsibility)	President	General Manager	Finance Manager	Chief Accountant	Chief Engineer	Construction Manager	Asst. Chief Eng.	Chief Estimator	Procurement Manager	Personnel Manager	Project Manager	Project Engineer	Planning/Sched. Eng.	Cost Engineer	Estimator / QS	Safety Engineer	Accountant	Purchasing Agent	General Supdt.	Field Office Engineer	Field Engineer	Superintendents	Foremen	Subcontractor
1. GENERAL MANAGEMENT																								
set out company objective	C,E																							
formulate company plans & strategies	C,E																							
responsible for company growth	C																							
determine company policy		C,E																						
marketing	A	C,E																						
decide to tender		C			H	A		E																
tender adjudication	R,A	E			H	A		D																
analyze status of projects	R	R	R		R	R																		
review business forecast & legislation	R	R	R			R																		
advise and assist key personnel	A	A																						
2. FINANCING/ACCOUNTING																								
financial planning, admin. & control	A	A	C,E																					
advise key personnel on financial matters			A																					
project's budgeting			A			A					C				E									
issue project's financial statement	R	R	R	R		R					C,R						E							
develop accounting procedures				C,H																				
direct accounting functions				C,H																				
company accounts				C,H																				
administration				C																				
project accounts/records/costs											C						E							
supervise timekeeping, payroll										A	C						E		A		D		D	
receive/process invoices and vouchers																	E							
record money committed/approved											C						E							
3. ADMIN. & PERSONNEL MANAGEMENT																								
hiring personnel, general										C,E														
hiring & training personnel, engineering					H		A			C,E														
hiring & training personnel, construction						H				C,E	A													
arrange training for personnel										C,H														
arrange safety facilities										A						H								
leveling project's labor and manpower											C								A					
perform labor relations such as interpreting																A								
union regulations, settling dispute, etc.																								
4. ENGINEERING																								
Engineering																								
engineering & design operations, home office					C,H		A																	
advise key personnel on technical matters					A		A																	
engineering & design operations, project's											A	C,H												
liaise field and office engineering												H												
handle change orders, work orders, claims							R,A				C	H								E				
handle design, drafting & shop drawing											A	C,H								E				
coordinate drawing, papers and submittals											C	H									A			
Estimating																								
analyze tender documents					C	R	A	R,H																
calculate required rates								C,A							E									
prepare net cost estimate								C,H							E									
analyze post-bid rates								C,R							E									
advise clients on cost reduction measures					C			A																

Fig. A1 (*continued*).

PERSONNEL vs. FUNCTIONS MATRIX (M-1)

Legends:
A= advisory/assist E= execution
C= control responsibility H= handle
D= data provisions
R= review & analyze

Function/Activity	Responsibility	President	General Manager	Finance Manager	Chief Accountant	Chief Engineer	Construction Manager	Asst. Chief Eng.	Chief Estimator	Procurement Manager	Personnel Manager	Project Manager	Project Engineer	Planning/Sched. Eng.	Cost Engineer	Estimator / QS	Safety Engineer	Accountant	Purchasing Agent	General Supdt.	Field Office Engineer	Field Engineer	Superintendents	Foremen	Subcontractor
MANAGEMENT LEVEL:		Top					Construction					Project								Functional					
project's estimating									A			C,A	H			E					D				
make quantity survey from drawings													C			E					D,E				
subcontract estimate												C	H			E									
Planning																									
prepare pre-tender programs						C	R,A							E											
prepare contract programs						C	R,A							E											
prepare method statements						C	R,A						H	E											
project's planning and scheduling						A	R					C,A	H	E		D									
prepare project's schedule for resources												C	H	E											
develop delivery schedules												C	H	E											
prepare project's weekly/monthly schedule												C	H	E											
expand/monitor preliminary schedules into detail schedules													C							A		E			
Cost Control																									
find economical men/machines/materials												C	A		E										
prepare all cost reports							R					C,R	A		E										
prepare cost engineering procedure												C	H		E										
prepare accounts/cost codes classifications					C								A		E										
cost distribution of labor/equipment/material													C		E										
analyze & control cost												C,R	A		R,E										
maintain cost records & reports												C	H		E										
forecast project's financial outcome			R	R	R		R					C,R			E										
monitor project's weekly labor, material, & equipment cost												C,R	A		E	D									
Quantity Surveying																									
measure work & payment estimate												C	H			E									
prepare/agree valuations												C	H			E									
prepare cost /value reconciliation												C				E									
agree final accounts												C	H			E									
Safety																									
implement safety programs on the project																	C,E								
make accident reports																	E								
take charge of explosive/blasting/safety												C					H								
administer safety enforcement																	H							E	
5. CONSTRUCTION/OPERATIONS																									
Construction Management																									
manage construction operations							C,H																		
develop construction methods						H	C						D												
supervise subs selection and negotiation							C,A			A		H				D									
procurement of resources							C,H					A													
supervise building production, all projects							C					H													
liaise with architect/client, all projects							C,H					A													
Procurement																									
obtain quotations										C,A		A		D	D	D			H						
assist supplier/subs on technical matters										C,A		A	D												
negotiate with sub-contractors/suppliers										C		A							H						
prepare/approve procurement contracts										C,A		A							E						
project's purchasing/expediting/inspection										A		C							H	A		A			

Fig. A1 (*concluded*).

PERSONNEL vs. FUNCTIONS MATRIX (M-1)

Legends:
A= advisory/assist E= execution
C= control responsibility H= handle
D= data provisions
R= review & analyze

MANAGEMENT LEVEL:		Top					Construction					Project								Functional					
Function/Activity	Responsibility	President	General Manager	Finance Manager	Chief Accountant	Chief Engineer	Construction Manager	Asst. Chief Eng.	Chief Estimator	Procurement Manager	Personnel Manager	Project Manager	Project Engineer	Planning/Sched. Eng.	Cost Engineer	Estimator / QS	Safety Engineer	Accountant	Purchasing Agent	General Supdt.	Field Office Engineer	Field Engineer	Superintendents	Foremen	Subcontractor
coordinate project's volume purchases										C,A		A							H	A					
maintain project's source files												C							E						
arrange transportation & routes										C									H						
order materials										C,A		A							E						
chase materials										C									H						
Project Management																									
project completion												C,H	A							E					
coordination (field, engineering, client, union)												C,E													
report project's progress/potential problems							R					C,R	H,R								E	D	D	D	
prepare project's progress & status reports							R					C,R	H	E											
job records, periodical reports, subs records													C,A								E	D	D	D	
progress photographs												C	H								E				
Site Management																									
field work, field survey, layout, etc.												C	A							H		E			
check progress of subcontractor																				H		A			
organize/supervise supdt./foremen/subs												C								H					
implement management decisions, like constr. methods, schedules, safety, etc.												C								E					
monitor preconstruction activities like preparing preliminary schedule, obtaining permits, job staffing, insurance, etc.												C,A								A					
supervise & organize the work of foremen, and equipment, materials, and services												C,A								C,A			H		
direct all pre-construction activities												C,A								C,A			H		
direct inspection												C										H	A		
concrete pours & quality control												C	A									H		E	
complete punching lists/operating data												C,R	R							A		A	E		
organize employee engaged in a craft																						A	A	H	
read/interpret drawing, blueprints, & specifics																						A		E	
allocate, assign and inspect work																						A		E	

Fig. A2. Summary personnel vs. functions matrix M-2.

PERSONNEL vs. FUNCTIONS MATRIX (M-2)

Legends:
A= advisory/assist E= execution
C= control responsibility H= handle
D= data provisions
R= review & analyze

Function/Activity \ Responsibility	Construction Mgr	Chief Engineer	Procurement Mgr	Project Manager	Project Engineer	Planning/Sched. Eng.	Cost Engineer	Estimator / QS	Accountant	Purchasing Agent	Field Office Engineer	Field Engineer	Superintendents	Foremen
Engineering														
project's engineering & design operations				A	C,H									
field and office engineering liaison					H									
change orders, work orders, claims				C	H						E			
design, drafting & shop drawing				A	C,H						E			
drawing, papers and submittals				C	H							A		
Estimating														
project's estimating				C,A	H			E			D			
quantity survey/estimate from drawings					C			E			D,E			
subcontract estimate				C	H			E						
Planning														
project's planning and scheduling	R	A		C,A	H	E		D						
project's schedule for resources				C	H	E								
delivery schedules				C	H	E								
detail schedules					C							E		
Quantity Surveying														
work measurement & payment estimates				C	H			E						
valuations preparation				C	H			E						
cost /value preparation				C				E						
final accounts agreements				C	H			E						
Construction Management														
construction operations management	C,H													
construction methods development	C	H			D									
subcontractor selection and negotiation	C,A		A	H				D						
procurement of resources	C,H			A										
building production supervision	C			H										
architect/client liaison	C,H			A										
Procurement														
quotations requests/receipts			C,A	A		D	D	D		H				
technical assistance to subs/suppliers			C,A	A	D									
negotiation with subs/suppliers			C	A						H				
procurement contracts/specs approval			C,A	A						E				
project's purchasing/expediting/inspection			A	C						H		A		
transportation & routes arrangements			C							H				
materials order			C,A	A						E				
materials chase			C							H				
Project Management														
project completion				C,H	A									
project's progress/potential problem reports				C,R	H,R						E	D	D	D
project's progress & status reports	R			C,R	H	E								
progress photographs				C	H						E			
Site Management														
field work, field survey, layout, etc.				C	A							E		
subcontractors' progress check												A		
punching lists completion				C,R	R							A	E	
subcontractors organization & coordination												A	A	H

Fig. A3. Personnel vs. information needs matrix M-3.

PERSONNEL vs. INFORMATION NEEDS MATRIX (M-3)

Information Needs / Infoneed By	Construction Mgr	Chief Engineer	Procurement Mgr	Project Manager	Project Engineer	Planning/Sched. Eng.	Cost Engineer	Estimator / QS	Accountant	Purchasing Agent	Field Office Engineer	Field Engineer	Superintendents	Foremen
Estimating / Quantity Surveying														
work item lists					x		x	x						
bill of quantities (item & quantity)	x		x	x	x	x	x	x	x	x		x	x	x
item cost	x		x	x	x		x	x	x	x				
cost summary	x	x	x	x	x		x	x	x	x				
budget for a trade			x	x				x		x				
start and end dates of trades			x	x	x	x		x				x	x	x
sub-bid due dates			x	x				x		x				
subcontractors/suppliers directory			x					x		x				
bid receipt dates			x	x				x		x				
bid amounts (individual bidder/trade)			x	x				x		x				
bid comparison or summary			x	x				x		x				
bidder ranking lists	x		x	x										
selected subcontractors/suppliers lists	x		x	x	x			x	x	x			x	x
progress measurements								x				x		
pay estimate number & date								x						
monthly work progress						x		x					x	
quantity of materials stored at sites								x		x			x	
value of materials stored at sites								x						
monthly valuation and report	x			x	x			x	x					
subcontract estimate								x	x					
Planning														
approval time for submittals				x	x	x				x				
delivery time of an item			x	x		x				x				
time impact by change orders				x	x	x								
revised completion date of project	x	x	x	x	x	x				x			x	
Engineering														
shop drawing lists				x	x					x	x		x	
shop drawing submission due dates					x						x			
shop drawing subcontractor/supplier			x		x					x	x			
status of shop drawings				x	x					x	x		x	
lists of approved shop drawings			x	x	x					x	x		x	
shop drawing approval delay time				x	x									
requests for information (RFI) lists		x		x	x									
RFI initiator's name				x	x									
contents of RFI				x	x									
date of RFI				x	x									
status of RFI		x		x	x									
response time of RFI				x	x									
RFI responding person					x									
outstanding RFI		x		x	x									
change order lists		x	x	x	x			x	x	x			x	x
change order details		x	x	x	x			x	x	x			x	x
subcontractor affected by change order			x		x				x	x			x	
change order value			x	x	x			x	x	x				
change order contract time impact				x	x	x								
status of change orders		x	x	x	x				x				x	
revised total contract price	x			x				x	x					

Fig. A3 (*concluded*).

PERSONNEL vs. INFORMATION NEEDS MATRIX (M-3)

Information Needs / Infoneed By	Construction Mgr	Chief Engineer	Procurement Mgr	Project Manager	Project Engineer	Planning/Sched. Eng.	Cost Engineer	Estimator / QS	Accountant	Purchasing Agent	Field Office Engineer	Field Engineer	Superintendents	Foremen
revised completion date	x	x	x	x	x	x				x			x	
Procurement														
suppliers directory			x							x				
requirement dates of materials			x	x						x			x	
sample/approval requirements			x	x	x					x	x			
approval time for submittals			x	x	x					x	x			
delivery time of materials			x	x	x					x				
materials affected by change orders			x							x			x	
status of materials on job site				x		x		x				x	x	
quantity of materials required				x						x		x	x	
quantity of materials stored				x				x					x	
supplier of materials			x						x					
lists of spare parts required			x	x						x				
details of spare parts			x	x						x				
quantity of spare parts required & delivered			x	x						x				
quantity of spare parts balance			x	x						x				
location of spare parts stored										x			x	
supplier of spare parts			x							x				
Project Management														
daily work progress				x	x								x	x
equipment in use and idle on job site				x			x		x			x	x	x
daily labor force on job site				x			x		x				x	x
daily weather condition				x										
visitors on job site				x	x							x	x	
materials requirements														
lists of site photograph				x	x									
negative/roll number of photograph				x	x									
date and location of photograph				x	x									
purpose of photograph				x	x									
Site Management														
lists of defective work notice (DWN)				x	x						x		x	
details of defective work notice				x	x						x		x	
subcontractor responsible for DWN				x	x						x		x	
type of defects/rejection of DWN				x	x						x		x	
value of DWN				x				x						
punch lists and details item lists				x	x						x		x	
subcontractor responsible for punch list				x	x						x		x	
status of punch lists				x	x						x		x	
Administrative														
owners contact & phone	x			x										
architects/engineers contact & phone	x	x		x	x						x			
subcontractors contact & phone				x	x			x	x		x		x	
suppliers contact & phone			x	x	x		x			x	x		x	
correspondence in & out list	x	x	x	x	x	x	x	x	x	x	x			
contents of a correspondence	x	x	x	x	x	x	x	x	x	x	x			
origins of correspondence	x	x	x	x	x	x	x	x	x	x	x			
dates of correspondence	x	x	x	x	x	x	x	x	x	x	x			
file-location of correspondence	x	x	x	x	x	x	x		x	x	x			

Fig. A4. Document type vs. information contents matrix M-4. (TL stands for tracking log.)

DOCUMENT TYPE vs. INFORMATION CONTENTS MATRIX (M-4)

Information Contents / Document Type	Bill of Quantities	Bid Summary Sheets	Change Orders TL	Correspondence TL	Daily Site Report	Defective Work TL	Materials Stored TL	Monthly Prog. Report	Photographs TL	Punch Lists TL	Requests for Info TL	Shop Drawing TL	Spare Parts TL	Company Directory
Estimating / Quantity Surveying														
work item lists	x													
bill of quantities (item & quantity)	x													
item cost	x													
cost summary	x													
budget for a trade		x												
start and end dates of trades		x												
sub-bid due dates		x												
subcontractors/suppliers directory														x
bid receipt dates		x												
bid amounts (individual bidder/trade)		x												
bid comparison or summary		x												
bidder ranking lists		x												
selected subcontractors/suppliers lists		x												
progress measurements								x						
pay estimate number & date								x						
monthly progress estimates								x						
quantity of materials stored at sites							x	x						
value of materials stored at sites							x	x						
monthly valuation and report								x						
subcontract estimate								x						
Planning														
approval time for submittals												x		
delivery time of an item												x		
time impact by change orders			x											
revised completion date of project			x											
Engineering														
shop drawing lists												x		
shop drawing submission due dates												x		
shop-drawing subcontractor/supplier												x		
status of shop drawings												x		
lists of approved shop drawings												x		
shop drawing approval delay time												x		
requests for information (RFI) lists											x			
RFI initiator's name											x			
contents & dates of RFI											x			
status ans response time of RFI											x			
RFI responding person											x			
outstanding RFIs											x			
change order lists and details			x											
subcontractor affected by change order			x											
change order value			x											
change order contract time impact			x											
status of change orders			x											
revised total contract price			x											
revised completion date			x											

Fig. A4 (*concluded*).

DOCUMENT TYPE vs. INFORMATION CONTENTS MATRIX (M-4)

Information Contents \ Document Type	Bill of Quantities	Bid Summary Sheets	Change Orders TL	Correspondence TL	Daily Site Report	Defective Work TL	Materials Stored TL	Monthly Prog. Report	Photographs TL	Punch Lists TL	Requests for Info TL	Shop Drawing TL	Spare Parts TL	Company Directory
Procurement														
suppliers directory														x
requirement date of materials												x		
sample/approval requirements												x		
approval time for submittals												x		
delivery time of materials												x		
materials affected by change orders			x											
status of materials on job site							x	x						
quantity of materials required								x						
quantity of materials stored							x	x						
supplier of materials							x							
lists of spare parts required													x	
details of spare parts													x	
quantity of spare parts required/delivered													x	
quantity of spare parts balance													x	
location of spare parts stored													x	
supplier of spare parts													x	
Project Management														
daily work progress					x									
equipment in use and idle on job site					x									
daily labor force on job site					x									
daily weather condition					x									
visitors on job site					x									
materials requirements					x									
lists of site photograph									x					
negative/roll number of photograph									x					
date of photograph									x					
location of photograph									x					
purpose of photograph									x					
Site Management														
lists of defective work notice (DWN)						x								
details of defective work notice						x								
subcontractor responsible for DWN						x								
type of defects/rejection of DWN						x								
value of DWN						x								
punch lists and details item lists										x				
sub responsible for punch list										x				
status of punch lists										x				
Administrative														
owners contact & phone														x
arch./engineers contact & phone														x
subcontractors contact & phone														x
suppliers contact & phone														x
correspondence in & out list				x										
contents of a correspondence				x										
origins & dates of correspondence				x										
file-location of correspondence				x										