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Structured Methodology for Developing
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**STRUCTURED METHODOLOGY FOR DEVELOPING
CONSTRUCTION MANAGEMENT COST CONTROL SYSTEM**

By

Pankaj A. Jagtap

A THESIS

**Submitted to
Michigan State University
In partial fulfillment of the requirements
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ABSTRACT

"STRUCTURED METHODOLOGY FOR DEVELOPING CONSTRUCTION MANAGEMENT COST CONTROL SYSTEM"

By

Pankaj A. Jagtap

The complex nature of construction projects generates a significant amount of information which needs to be captured and analyzed for decision making in construction project management. An information system (IS), which manages these information handling requirements should be developed using a structured methodology. This thesis streamlines the IS development process in the construction project environment.

The objective of this research is to design a structured methodology for developing information systems in the construction project environment and apply that methodology to develop a cost control system for construction project owners. This cost control system is envisioned for a management team headed by a construction management firm in a construction management contract delivery system. An information system environment along with the phases and activities involved in a structured methodology are described in this research. This derived methodology is applied to develop a cost control system. Modeling techniques are used to represent the data flow and processes involved in different aspects of an owner's cost control system. The functioning of the cost control system is demonstrated by applying it to two case studies.

To My Parents...

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LIST OF ABBRIVIATIONS

IS	Information System
IT	Information Technology
CM	Construction Management
CMCC	Construction Management Cost Control
CMCCS	Construction Management Cost Control System
CMSDM	Construction Management System Development Methodology
MIS	Management Information System
AEC/CM	Architect Engineer Contractor/Construction Management
DFD	Data Flow Diagram
ERD	Entity Relationship Diagram

CHAPTER 1

INTRODUCTION

1.1 Research Area

1.1.1 Complexity in Construction Projects

Projects in the architecture/engineering/construction/construction management (AEC/CM) industry have significant information handling requirements for several reasons. They are complex, having many physical components such as structural elements, equipment and furnishings, and non-physical components such as schedules, construction methods and code requirements. Every new project is set in a new environment, resulting in new components and new construction methods. AEC/CM projects can last anywhere from a few months to several years. This means that information created at one point has to be represented and stored in some way until it is used later. AEC/CM projects are also characterized by the large number of organizations and professionals involved. Not only do some organizations generate information, which others use, but they also frequently exchange information back-and-forth. Finally, information from lessons learned in previous projects can be very useful for future projects [Breuer et al. 1994].

1.1.2 Information System in Construction

The timely acquisition and analysis of information becomes critical to the success of a project due to their magnitude and complexity. Managing such complex

AEC/CM projects is very difficult without a comprehensive management plan and a functional management information system (MIS). The management plan will establish the method for obtaining the program's schedule and cost goals, and determine the most efficient allocation of resources to achieve these goals. The MIS will provide the scorecard to determine how the project management team is progressing towards realizing the program's goals.

MIS is a very loosely used term in the construction literature. A management information system is an information system application that provides for management-oriented reporting, usually in a predetermined, fixed format [Whitten et al. 1998]. During the life cycle of a project, project plans are developed in the project planning phase and they become the basis for monitoring and controlling progress in the project control phase. Therefore, the project control system, which collects and analyzes information and helps management in decision making, is nothing but the project level MIS. More detailed classification of different information systems in construction is done in later chapters.

The project level MIS should be able to manage the enormous and complex sets of information generated in AEC/CM projects. Effectively managing this bulk of information to insure its availability and accuracy is an important managerial task. Poor and missing information could easily lead to project delays, uneconomical decisions, or even a complete failure at some point during the project life cycle. The accurate and timely information generated by the MIS becomes key to the success of any construction project. At the same time, too

much unorganized information presented to managers can result in confusion and paralysis of decision making. A listing of the most important information sets would include [Hendrickson et al. 1989]:

- Cash flow and procurement accounts for each organization**
- Intermediate analysis results during planning and design**
- Design documents, including drawings and specifications**
- Construction schedules and cost estimates**
- Quality control and assurance records**
- Chronological files of project correspondence and memoranda**
- Construction field activity and inspection logs**
- Legal contracts and regulatory documents**

Some of these sets of information evolve as the project proceeds. Different project participants use information from different viewpoints. For example, a construction management firm may utilize cost related information at the cost accounts level while a general contractor may look into productivity and cost of equipment. Different departments of the same organization use different types of information or they may use the same information in different ways. For example, an accounting department of the owner's organization would look into requisitions and cash flow forecasts, while an operations department would look into the overall project schedule and cost. Different levels of management use different levels of information such as a senior project manager who looks only at the multiple project milestone level schedule, while individual project managers look into project specific activity level schedules. Due to these different

applications of an information system in project management, successful development of an information system which would achieve its client's objectives, is one of the most essential tasks for effective project management. The construction industry is counting more and more on new developments in information technology (IT) for application and development of more project specific information systems.

1.1.3 Application of Information Technology in Construction

Information technology has become an integral part of construction project management. A computer on the project manager's desk has become a common sight in many construction organizations. Use of electronic mail is increasing day-by-day. Field managers are using portable computers to record field reports [Williams 1994]. Project managers are getting project information related to cost, time, quality and safety at their finger tips due to the development of the internet and company intranets [Mead 1997]. Computer integrated construction has become a buzzword in universities and project control departments of large construction organizations. More and more software packages are coming into the market to capture the industry requirements of information and communication between the project team members. Sales people are chasing the project controls professionals for demonstration of new software and technology. It's the start of a new era in construction history where projects are becoming more and more dependent on the information system [Schultz 1997]. But are we getting the results of the technology revolution? Are we successful in

actual implementation of this technology? Have we achieved the dream of a paperless office? Has the computerized integrated system come to reality? Are we sharing the project documents electronically among all the project participants? Unfortunately the answer to these questions is frequently "NO". Companies are spending thousands of dollars on software and hardware on the basis of promises made by sales people. After facing problems with the implementation of software, companies are signing technical support contracts and paying more money to the software companies and hiring more people to make the software work for them. Most of the information systems are underutilized or overused to satisfy the information requirements. Most of the project teams are not satisfied with the state of the information system they have and have reverted back to the old way of hard copies and written notes.

On the basis of the author's experience in the construction industry, the problem seems to be more with the implementation of technology than with the technology itself. Keeping up with the pace of an ever-changing computer technology is the construction industry's greatest challenge. Past decades were spent in convincing the construction community about the advantages of computerized information systems. It is the researcher's belief that most people in the construction industry are convinced of the advantages of using information technology, but are not successful in its implementation. Now it's an era of technology implementation. Most problems of inefficient information systems have origin in the "Ad hoc" methods of system development. Successful implementation of IT solutions requires a methodical approach in system

development for the construction industry. The construction industry needs to consider technical as well as managerial issues while implementing IT. It requires understanding of the unique requirements of the construction industry and a grasp of the ever changing IT industry. [Breur 1993, Sadri et al. 1925]

1.1.4 Structured Methodology

System problem solving is the act of studying a problem environment in order to implement corrective solutions that can form a new or improved system. Most system analysts use some form of system problem-solving approach called a system development life cycle. A system development life cycle is a systematic and orderly approach to solving system problems. While a wide variety of problem solving approaches have been tried, it usually incorporates the following problem-solving steps [Whitten et al. 1998].

- **Survey phase** includes activities such as defining the scope of the system, identifying the time required for development of the system and allocating the budget for the system development.
- **Study Phase** includes activities such as understanding the current system and understanding the user requirements for the new system.
- **Definition phase** includes accurate representation of user requirements in terms of data and process flows within the information system.
- **Configuration phase** includes identifying candidate solutions, evaluating feasibility of these solutions and identifying the target system.

- **Procurement phase** includes purchase of software and hardware.
- **Design phase** includes designing of reports, user interfaces and interfaces between different sub-systems for developing an integrated system.
- **Construction phase** includes installation of software and hardware, developing user interfaces, and customizing the system for the project requirements.
- **Delivery phase** includes testing the new systems for required performance and transferring day-to-day business information.
- **Support phase** includes activities such as training employees for the new system, documenting procedures and fixing implementation bugs.

Structured methodology is a systematic problem solving approach for development of information systems. Every industry and system analyst uses some variation of structured methodology, which is based on the system development life cycle. Successful development of an information system in the construction industry depends heavily on development of such a structured methodology, which is most applicable to the construction industry.

1.1.5 Domain Construction Environment

The domain construction environment needs to be explained to facilitate understanding of the project variables for the targeted industry. The domain construction project is a typical mid-size building construction project with a dollar value of more than \$50 million, and spanning more than two years for construction. The project delivery system for this project uses a professional

construction management (CM) organization. In this contractual system the construction manager leads the team of owner, designer and construction manager, and therefore becomes responsible for the overall coordination of the construction operation while controlling cost, time, quality and safety of the construction project [Barrie et al. 1993].

A project control system should have two levels with separate orientation [Burger 1973]:

1. Project control system level, which will cover all central and operational aspects of the project
2. Management information system, which provides both the upper structure of the system, used by senior project manager, and reporting, which interfaces with the client, architect/engineer, and other outside project groups.

The owner's level MIS, which helps higher level management in decision making and interfacing with other external entities, is as important as the operation level MIS. In case of construction projects managed by a construction management contract delivery system, the owner's level MIS helps the owner's management team headed by a construction management organization in decision making. The owner's level MIS can consist of different integrated subsystems such as cost control, progress control, contract administration and cash flow management systems. For example, an owner's cost control system will look at the cost control from the owner's point of view rather than the accounting details of the contractors.

1.2 Problem Area

1.2.1 Requirements of MIS

The successful execution of construction projects depends heavily on the project specific management information system for accurate and timely information used in decision making. A project level MIS that can effectively manage all administrative work, progress control information, and cost control operations is essential for successful management of construction operations. Many construction projects run over budget or over time due to their poor information systems.

Capturing data at the right time and place is essential for generating useful MIS reports. For example, consider an activity such as "pour concrete for slab-on-grade". One needs to capture the amount of concrete poured for that activity at the right time and report that information to the upper management in terms of consumption reports so that appropriate actions can be taken. But if the reports are generated once per month, then any necessary corrective action could not be taken in time to prevent the possible extra consumption of concrete. Also, if the excess consumption is not attributed to the detailed cost account, it would be difficult for management to identify the problem area precisely and the consumption of extra concrete will go unnoticed. This example shows the importance of designing an information system which can capture data and produce accurate and timely information for decision making.

Let's analyze one more example. No construction project is completed without change orders and extra work. In the case of change orders, the owner's

level MIS should report to the management team that works on behalf of the owner about the possibility of extra work, and any extra work should reflect in the budget and cash reports. If such information is not transformed and reported to the management team, project costs would increase without knowledge of the management team. These examples show how important it is to have an MIS which can report timely and accurate information to the management team for decision making. Absence of an effective information system can contribute to time and cost overruns of construction projects. Therefore, one needs to identify a structured MIS development process, which can lead to development of a successful project specific information system to provide timely and accurate management reports for decision making.

1.2.2 MIS Implementation Difficulties

In the present competitive environment, construction organizations are depending on information systems for a competitive advantage and quality customer service. Therefore, upper level management is promoting the use of information technology to develop a state-of-the-art information system for construction projects. But in spite of management support, organizations are not achieving the expected results [Breuer et al. 1994]. The reasons for this mismanagement of information systems are the implementation methodologies used by the developers. The implementation depends substantially on information requirements, which are both project and company specific. On the basis of these requirements, one needs to determine the information flow among

the organizations, as well as the information architecture and IT tools which will satisfy these requirements. The complexity involved with development of an MIS should be examined in detail to understand the problem areas.

Depending on the type of project, different types of IT tools need to be selected. For example, estimating software, which is effective for building construction, may not be the best option for highway construction. The size of a construction project affects the amount of data generated by the information system even if projects are of same type. Therefore, the selected IT tools should be able to manage the amount of data for a given project without being an overkill for the project. Construction projects have different delivery systems such as traditional AEC/CM, construction management system, and program management or design-build. Depending on these delivery systems, the number of organizations involved in a project and their roles and responsibilities vary. This variability leads to changes in information flow among the agencies involved. Therefore, the selected IT tools should be able to manage these process requirements.

Different organizations have different management styles. Some organizations rely on a centralized system, while others believe in project level management. Also, team members on a given project have different methods of performing their work. The organizations also have different approaches toward information technology. Management support affects the implementation of an information system considerably. While selecting a management information system, It is also important to consider technical knowledge available in the

organization. Otherwise much time is spent on training people which leads to a slow rate of system implementation. The difficulties in accepting new technology, changed working conditions and the company culture also affect the system implementation.

When selecting software and hardware based on the project requirements, one also needs to consider different technical and monetary issues. The most important decision is whether or not the return on this investment justifies the benefits. One needs to conduct a detailed return on investment analysis to see if selected tools will provide the optimum solution. Also, system analysts need to study software and hardware related issues such as availability of technical support and training manuals, as well as long term use of software. One also needs to decide if the proposed IT solution should be developed in-house or whether commercially available software solutions should be implemented. In the case of a system where multiple tools are utilized, one needs to analyze whether a computer integrated system or "stand-alone" function-specific system would be a better choice. Also, different data-related issues such as reporting related features and the format in which data is generated become a part of the system selection process. If an organization has projects at different geographical locations, then networking needs to be implemented to achieve data transfer between the head-office and various project locations. In the case of networking, different issues related to data security, data access, and data transfer need to be resolved for a successful network implementation.

In an industry where so many variable factors exist related to selection and implementation of an information system, one needs to use a methodical approach in the system development and implementation process. Most of the time these factors of system design and implementation are not considered while developing an information system. Typically proven software solutions available in the market are used for the development of information systems. These solutions are designed to support general user requirements, however they typically are not able to satisfy user specific requirements of an MIS. This strategy leads to an unsatisfied project team with an inefficient disintegrated information system. Therefore, a precise solution for the requirements of an information system requires a systematic, methodical approach of system development. It's essential to follow the different phases of "system development life cycle"; to achieve the results required of an information system.

1.3 Research Objectives

This research is an attempt to streamline the process of successful development and implementation of IT solutions in the construction industry. The objectives of this thesis are threefold -

[A] Apply an information system framework to define a structured methodology for developing information systems in the construction industry.

[B] Apply the newly developed structured methodology to the development of an owner's cost controls system for the domain construction project. Development of this cost control system will demonstrate the application of the newly developed structured methodology in the construction industry.

[C] Evaluate the functioning of the cost control system and proposed system development methodology by applying it to two case studies and demonstrating its benefits compared with the traditional systems. This will show the application of a cost control system and system development methodology in the construction industry.

1.4 Research Methodology

The first step in this research is to define the information system environment in the construction industry. Based on the literature review, different types of information systems such as cost control, progress control, contract administration, design and estimation, in the construction industry will be identified. The project environment in which systems are developed will be described. Also, different possibilities of system development such as implementing a new system, or implementing changes and modifications to an existing system will be identified. People involved in the development such as system users, system owners, system analysts, and the project support group will be identified and their functions will be described. This step will also include identification of building blocks for information systems in the construction industry such as data generated, processes involved, interfaces and geography involved in development of information systems.

After understanding the system development environment, a complete literature review will be conducted to identify different system development methodologies. A methodology, which can be applied to construction projects, will be selected based on the literature review. A system development life cycle of the selected methodology and all its phases and activities will be applied to the construction environment to develop a structured methodology for the system development process in the construction industry.

This structured methodology will identify the critical phases and activities, which are critical for development of an information system in the construction

industry. The modified system development life cycle will guide professionals involved in systems development in the construction industry by explaining different phases and activities involved in system development. It will define people involved, their responsibilities, and activities in each phase. It will also explain the decision making required in each of these phases.

After defining the structured methodology, this methodology will be applied to the domain construction project to develop an owner's level cost control system. The owner's cost control system is selected mainly due to the importance of cost control operation in successfully completing construction projects of large size. While applying this methodology a literature review will be conducted to get more understanding of the construction management type of contract administration system. This literature review will give details about the construction environment, system users, system owners and the information and data requirements for cost control system.

A leading off the shelf software package, EXPEDITION¹, by Primavera Systems Inc. will be studied in detail to understand the functioning of a commercially available, state of the art software package. This software will be analyzed for different types of information handling, data flows, process flows, decision making and basic activities involved in the cost control operation. EXPEDITION is a multiuser, multiproject, client/server database product that helps project participants control contract changes and submittals.

¹ Trade names are used in this thesis solely to provide specific information. Mention of a product name does not constitute an endorsement of the products by the author to the exclusion of other products not mentioned.

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It provides a centralized way to store, organize, and track project information.

As a part of a structured methodology, data and information flow between and within different parts of a cost control system such as contracts, change orders, invoices, and requisitions will be represented using data flow diagrams. An Entity-Relationship (E-R) diagram, which shows relationships among data, will also be developed [Appendix A]. An E-R diagram can be used for development of database cost control applications. The intended cost control system is envisioned to include:

- Development of project budgets from estimates
- Development of contracts and purchase orders
- Development of cost codes in cost worksheets
- Cost updating with requisitions, invoices, and material delivery
- Budget changes with change orders, proposals, and trends
- Reporting variances, forecasting and status reporting
- Links from a scheduling system

Two case studies will be conducted to evaluate the functioning of proposed system development methodology. In these case studies, two construction projects similar to the domain construction project will be selected and their cost control systems will be analyzed. The owner's cost control system and the system development process employed will be studied in detail to understand the structure and method of their cost control system. This study will

identify the functioning of cost control systems and their relationships with the system development methodology. After studying and defining the cost control systems in these case studies, some examples of data and information flow such as processing change orders or possible rises in fuel prices will be selected to evaluate the functioning of the system. The response to these examples by cost control systems will be studied to evaluate the performance of the system. If those systems fail to process the data and generate adequate decision-making information, the same examples will be tested in the newly developed cost control system. This test will demonstrate the benefits of the proposed cost control system and system development methodology over traditional systems and processes. These observations related to the application of the proposed system development methodology and cost control system will be discussed with the system developers for the case study projects. Their comments will be summarized to get industry response to the proposed system development methodology. On the basis of case studies, some adjustments may be done to the proposed structured methodology and cost control system.

1.5 Expected Results

This research is an effort to define the information system framework in the construction industry and to state the phases and activities involved in a structured methodology for developing information systems in construction. It also demonstrates the application of a structured methodology by developing a cost control system for a construction management delivery system.

The following items will be developed through this research:

- An information system framework for the construction industry which will include different information systems as well as their applications, owners, users and interrelationships in the construction industry.**
- A structured methodology with all phases and activities of a system development life cycle for developing an information system in the construction industry.**
- A description of the process of information system development for cost control systems. This includes representation of data and information flow within a cost control system and its components using flow charts or data flow diagrams.**
- A design of a database application using an Entity-Relationship (E-R) diagram. An E-R diagram gives relationships between different data elements which can be used for database application development.**
- A decision making model for setting up a cost control system. This includes all the decisions that a project team needs to make while developing a cost control information system.**

CHAPTER 2

EXISTING RESEARCH AND COMPUTER APPLICATIONS

2.1 Introduction

Construction projects have been using computerized information systems for almost four decades. The selection of the medium for managing information has depended primarily on the amount of information, the available technology and the technical knowledge of the organization. As the size of their construction projects started to grow, construction organizations have started to move towards computerized information systems. [Paulson 1996]

The computer applications in construction began evolving in the late 1950s, and have evolved steadily ever since. The next two decades saw steady progress, particularly in the home-office applications such as accounting and finance, though the impact did not match the revolutions that took place in banking, airlines and telecommunications. The project-oriented applications such as CPM scheduling, estimation and simulation continued to evolve. But these applications did not become popular because of the associated large data handling requirements, initial problems related to costs of and access to computer hardware, complexity of the software, difficulties with interpreting output, as well as gaps in training for site-level people who were almost totally unfamiliar with computers. In the 1980s, microcomputers became widespread and rapidly decreased in cost. Also, some powerful but easy-to-use application

development software, such as spreadsheets and databases, was introduced. This new software greatly increased the number of people who could economically create applications, which, in turn, lead to general awareness and knowledge of computers in the construction industry [Paulson 1992, Syal 1992].

Application of a computerized information system has been a major area of research in construction management. With new developments in information technology, other industries such as manufacturing and retailing were the first ones to take advantage of technological applications. After observing these applications, researchers in the construction industry started concentrating on different applications of information technology in the construction industry. As the applications started to increase, construction firms started to find more and more problems with various issues related to management of computerization. A significant amount of research has already been done to show problem areas and the possible solutions in those areas such as training, quality standards, vendor-user relations and purchasing of software. Some researchers have also focussed on the core issue of the system development process which involves all the above mentioned issues.

The objective of this literature review is to summarize the already accomplished work and existing software in the fields of system development, information technology applications and application-related issues in construction management.

2.2 Information System in Construction Management

2.2.1 Information System Applications

Considering the enormous amount of information flow among different personnel involved in construction, research was conducted to identify their information requirements [Tenah 1986, Tenah 1984]. This research defined the information requirements, functions and the required types of reports for most positions in a construction company including president, directors, project managers and site superintendents.

Most computer application development has taken place in a fragmented fashion and, as a result, different developers have focussed on different tasks associated with the project planning process such as cost estimation and construction scheduling [Syal 1991]. Computer Integrated Construction (CIC) applications started to emerge in the early 90s and became a major area of research in construction management. Many researchers have shown the application of information technology in the integrated applications for design and construction [Ahmed 1995].

2.2.2 Information Technology Applications in Construction

This is more of an applied area of research where researchers from both academia and industry have contributed to the application of information technology (IT) in construction management. Work has been done in different segments of IT such as microcomputers, networking and the latest technology such as Internet.

When the microcomputers became popular in mid 80s, work was done to list different possible applications of microcomputers in construction operations done [ASCE Task Committee 1984, Barnes 1993]. Some database applications were suggested to generate daily site reports [Russel 1993]. Some researchers showed the application of microcomputers and networking for managing computerized specifications and sharing them with other project partners [Bosserman 1985]. Some researchers showed the possible applications of computers to keep safety records [Stanton 1990].

Inspired by the application of IT in some other industries, researchers tried to demonstrate IT applications of bar coding and electronic data interchange [EDI] technology in the construction industry. Bar coding [Stukhart 1989] can be utilized for inventory control at a job site where EDI can be used to exchange project related data such as purchase orders, invoices, and requisitions electronically among project participants [Gibson 1991]. Some researchers showed the application of portable computers and hypermedia in construction management [Williams 1994]. Considering the new trend in networking, a case study was developed to demonstrate the process of transferring from a microcomputer environment to a client-server networking environment [Zeremba 1993].

The latest focus on IT applications is on the internet/intranet applications in construction management. Internet is perceived by some as a channel of communication which can solve most of the communication problems in construction management [Schultz 1997]. Researchers in the AEC environment

are working to define the communications problems and possible solutions using different internet tools such as project level intranet, email, FTP, VRML, GroupWare, virtual white board and video conferencing. Some work has been done in the development of a detailed design for a project level intranet [Mead 1997]. This work proposed two models of project level intranet:

1. Basic Model, which can be used for description and marketing purposes, and also can be accessed by anyone on the internet.
2. Expanded Model, which can be used to enhance the performance of the project team. This model can be accessed only by the project team, and can contain information about schedules, budget and project progress.

2.2.3 IT Application Issues in Construction Management

Researchers have tried to address various issues related to successful application of IT tools in the construction industry. People in the construction industry and especially in the construction-consulting environment have contributed most to the work related to actual application issues, which is evident from the following literature review.

Some researchers have focussed on fundamental issues such as strategic planning of IT resources for construction [Terry 1993]. This research includes discussions of issues such as timing of computerization, identification of objectives of computerization and the overall business-focussed strategy. It emphasized the importance of understanding the expectations from computerization and planning for it.

Some researchers have focussed on the issues involved in transferring from one IT platform to another such as, microcomputers-to-network workstations and possible problems with it [Kostem 1993].

Research has been done in several different implementation areas such as vendor-user relations in which the authors describe the issues related to technical support, service and quality of software [Tonias 1992]. Some work has been done on the usage of IT resources and procedures for better management of these IT resources [Pixley 1992]. Some work has been done in the area of acquisition of hardware resources for IT applications [Lackowitz 1992] and its usage [Jan 1991]. Some researchers have investigated the legal aspects of software usage [Najafi 1991]. Some work has been done in quality assurance procedures while using IT software [Fenves et al. 1979]. Other research has been done in computer selection process, while some work has been done on issues related to providing in-house computer services [Brown 1980].

Some researchers have studied the managerial issue related to IT implementation and discussed its importance [Breuer et al. 1994]. They discussed different issues related to planning, organizational, development and management. This work gives a good insight into all the possible managerial issues such as:

- Planning which includes the roles of IT, leadership, identifying IT opportunities, resource commitment and innovation versus imitation.

- **Organizational issues** which include different perspective on IT, changes in organizational structure, role of user versus role of IT specialists, and the threat of IT
- **Development and Managerial issues** which include make or buy, implementation process, result control system, training and education, and operational dependence.

2.3 System Development in Construction

Not much construction management research literature is available related to the process and methodology of information system development. Some researchers have pointed out the importance of following different phases of system development such as planning, analysis, design, construction and support [Paulson 1995]. But these steps are very generic steps involved in any project management operation. Most of these recommendations are based on the extensive research done in the field of MIS, which has not focused on the requirements of the construction industry. Also, no work has been done in the field of selection of appropriate methodologies for different project environments.

Sadri et al. [1993], described the requirements of information systems and system development phases and activities. Their work proposed the following minimum requirements of design specifications for development of information systems.

- **Timeliness:** Information systems should be able to generate information that is available at different levels of abstraction and can be generated at the required time.
- **Quality:** Information produced should be accurate.
- **Integrity:** Information should be correct and validated by business rules.
- **Value:** Information should be produced in an understandable format.
- **Effectiveness:** Information should be generated using technically efficient and effective manners.

Their work also proposed the following "conceptual integration system" for development and implementation of information systems. This information system development is specifically for construction organizations.

- **Planning:** This phase includes activities such as defining business strategy, assessing existing information systems, developing information needs reports, bench marking best practices and developing information system plans.
- **Operation Analysis:** This phase includes activities such as defining operational departments, identifying data sources, modeling future business operations, documenting technical requirements and doing a cost-benefit analysis.
- **System design:** Identifying technology, developing a process and information model, deciding procedural and cultural changes, designing system tests, and designing training.

- **Implementation:** Developing implementation procedures, implementing design specifications, testing systems, conducting training, and monitoring performance.

2.4 Cost Control System

Although construction project management can be divided into a number of functions, planning and controlling are considered to be the primary ones responsible for the success of a construction project. The planning and controlling functions related to the cost and time aspects of construction projects have always been of interest to construction researchers and practitioners. Construction project planning provides the performance standards against which project progress is measured and analyzed during the construction project controlling stage [Syal 1992].

Project control systems should have two levels with separate orientations [Amadeus et al. 1973]:

1. Project control system level, which will cover all control and operational aspects of the project
2. Management information system, which provides both the upper structure of the system, used by a senior project manager, and reporting, which interfaces with the client, architect/engineer, and other outside project groups.

Zapalac et al. [1994] explained the process of MIS development for a management team headed by a construction manager/ program manager in multiproject programs. Development of a program schedule and loading that

schedule with project costs and funding sources is explained. The process of managing and updating cash flows using both cost and funding loaded schedules is also explained.

Some work has been done in defining the reporting and analysis required for cost management at the job or management level. Some of these requirements are as shown below [Paulson 1976]:

- **Selectivity and subreporting:** Required information at the required level of details
- **Variances:** Deviation between expected-at-completion cost and budgeted cost of a project.
- **Management by Exception:** Identify and isolate the most important information for immediate management action.
- **Forecasting and Trending:** Use forecasting of time and cost for the project to anticipate problems before they arise.
- **Feedback Time:** Prepare reports which provide useful information in time to make critical decisions.

2.5 Computer Applications for Cost Control System: EXPEDITION

"EXPEDITION: Contract Control Software" by Primavera Systems Inc. has the largest share in the market for contract administration software [Expedition 1996].

A cost control system is a part of the total contract administration system. Cost control systems for the owner's management team headed by a construction

management (CM) firm, needs only cost information for the different bid packages or contract levels.

EXPEDITION is a multiuser, multiproject, and client/server database product that helps to control contract changes and submittals. It provides a centralized way to store, organize, and track project information. Expedition consists of many interrelated "logs" that store information about construction projects such as submittals, transmittal letters, meeting minutes, contract terms, contract prices, invoices, requisitions, and changes. The whole structure of EXPEDITION can be divided into two parts. The first part is for managing documents such as letters, submittals, and reports. The second part is for organizing, managing and controlling project cost related items such as contracts, purchase orders, invoices, requisitions and change orders. This research work will design a cost control system, which will focus on these cost related items of EXPEDITION. The following is a list of cost related modules in expedition and their applications:

- **Contract/ Purchase Order:** EXPEDITION helps to organize and manage lump sum and unit price contracts and purchase orders (POs). Once a contract or PO is set in EXPEDITION, it can generate related submittals and requisitions, track changes, and monitor charges.
- **Material delivery:** EXPEDITION helps to manage construction material delivery and its effect on managing pay requisitions.
- **Invoices:** EXPEDITION helps to keep track of billing information by generating invoices for suppliers or contractors.

- **Change Process:** EXPEDITION helps to manage all types of changes in construction conditions by generating change orders, requests, notices and proposals
- **Requisition:** EXPEDITION helps to create requisitions and manage calculations related to contractor payments.
- **Cost Worksheet:** EXPEDITION's cost worksheet provides a central location where all of this information can be collected and tracked, and where financial status of the project can be quickly checked. The cost worksheet tracks proposed changes, actual changes, and trends as well as costs distributed from contracts purchase orders, invoices, and requisitions. The cost worksheet is used to closely track budgeted costs, committed costs, funding costs, actual expenditures, and budget revisions caused by changes.

Cost Management Process: Figure 2.1 shows the flow of activities and the actions, which need to be taken during the cost management process while using EXPEDITION. Contract cost management activities can be divided into two phases. The first phase includes preconstruction activities such as setting up the projects, contact of project participant organizations, and contract information. The second phase includes updating of contracts and cost related documents such as material delivery reports, requisitions, invoices, and change orders.

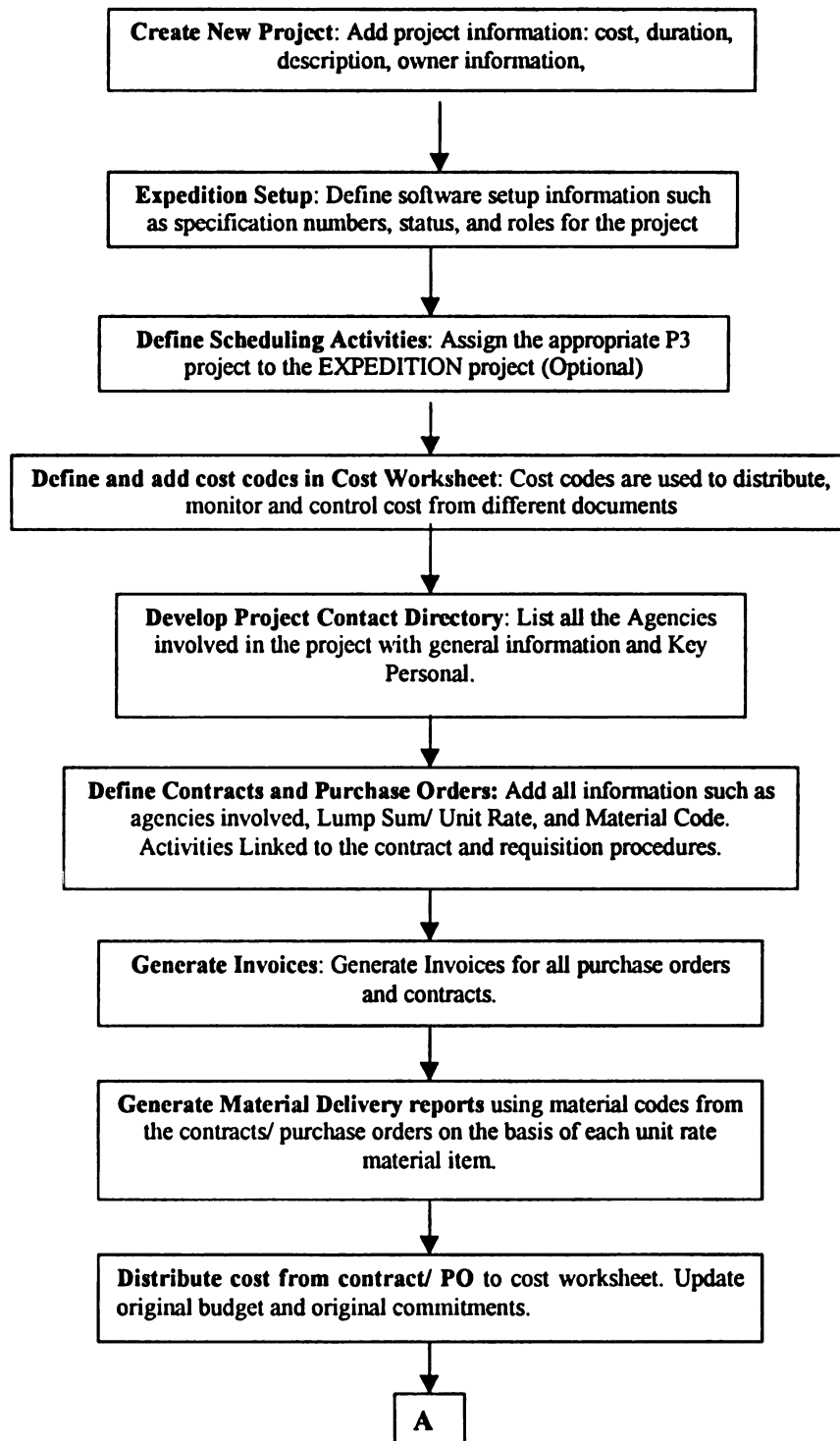


Figure 2.1 Cost Management Process in EXPEDITION

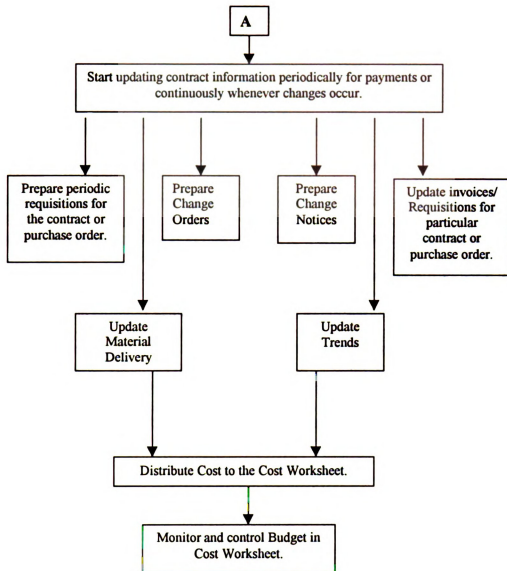


Figure 2.1 Cost Management Process in EXPEDITION (Continued)

2.6 Summary

This literature review describes the research work related to information systems and technology applications in construction management, and is a background for the work done in the remaining part of this research.

One needs to observe that a sizable amount of work has been done in the areas of IT applications in construction and in implementation issues related to information systems in construction management. It should also be observed that all of this work has been done in a very fragmented manner without looking into the core issue of information system development in construction management. It is this researcher's belief that all issues related to IT applications and IS implementations are sub-parts of the core issue of information system development, which has not been addressed by most research in the past.

CHAPTER 3

INFORMATION SYSTEM DEVELOPMENT ENVIRONMENT AND CONSTRUCTION MANAGEMENT PERSPECTIVE

3.1 Introduction:

Information systems are made up of four building blocks which are business data, the processes that mobilize data, interfaces that interact with the humans and other systems, and networks which connects users and system resources [Whitten et al. 1998]. People with many different perspectives interact with an information system. Therefore, before understanding the system development process, one needs to understand and analyze the system development environment, which is made up of system building blocks and the users. This chapter is aimed at providing that understanding of generic system development environment and its construction management perspective to understand what it means to the construction industry.

The next section describes various information subsystems involved in construction project management based on their primary functions. After defining these subsystems, they are classified in terms of different variables such as core functions and managerial activities as well as their place in the construction project life cycle to clarify the role of these subsystems in the formation of construction management information systems. Before describing the reasons for

system development, the basic contents of system development environments such as information system architecture and which people use information systems are discussed.

3.2 Information Systems in Construction Project Management

Construction project management is a part of almost all phases of a construction project life cycle. Information systems are used in different parts of a project life cycle to collect and analyze data and to help managers in decision making. These information systems which have emphasis on particular types of activities such as cost control and time control, can also be called information subsystems. Various combinations of these function-oriented subsystems form a construction management information system. Table 3.1 shows the list of information subsystems used in construction management as well as their contents and applications in construction management.

3.3 Classification of CM subsystems:

After identifying construction management subsystems, these subsystems are classified in four different ways on the basis of various parameters to identify their role and application in construction management. This information can help in identifying application of these subsystems in different construction project environments. The following sections describe these classifications which include:

- Project Life Cycle Classification
- Managerial Activity Classification
- Functional Classification
- Hybrid Classification

**Table 3.1 Construction Management Information Subsystems [Modified
from Paulson 1995].**

Information Subsystem	Contents	Function
Project Cost Estimating and Budgeting	All cost items including direct and indirect costs.	Detailed cost estimates are generated which are used to prepare a project budget.
Project Time Planning and Control:	All activities, durations, relationships, and resources required to complete those activities	Used to prepare a project time plan, which is also used for progress monitoring.
Job-costing and Cost Engineering	Cost accounts, and expected consumption and actual consumption of resources for each cost account.	Used to control consumption of resources compared to budget and helps managers to make timely and appropriate operational decisions.
Accounting and Payroll	Different charts of accounts	Works as an accounting system for internal and external management and reporting.
Material Management	Different material items, delivery schedule, and accounts payable information	Used to manage material acquisition and consumption processes.
Equipment Management	Equipment information, depreciation, cost	Used to manage the fleet of equipment throughout the organization.
Contract Administration	Information about contracts, purchase orders, invoices, change orders, payments, requisitions, and submittals	Used to keep track of all contract related costs and documents.
Company and project Finance	Company financial information, cash flow, target profits	Analyzes the project performance in terms of organizational goals and targets.
Human Resource Management	Employee information, wages and training data.	Used to manage human resources and training for better productivity.

3.3.1 Project Life Cycle Classification

Information subsystems can be classified on the basis of their position in a project life cycle. The subsystems can be divided into two major parts within construction project management. These are:

- **Project Planning:** Includes estimating, budget preparation, and time planning systems, as well as the quality plan, safety plan, and financial plan.
- **Project Control:** Consists of cost control, time control, project administration and resource management subsystems which include material management, equipment management, and human resource management (HRM).

3.3.2 Functional Classification:

One of the other common parameters is the functional subsystem. This classification is based on the principal functions performed by the system. People in the construction industry have been using and developing functional subsystems for last four decades. Some examples of functional subsystems are time planning and control, cost planning and control, project administration and resource administration subsystems.

3.3.3 Managerial Activity Classification:

Another way of classifying these subsystems is by the management activities performed by each subsystem. Overall functional management can be divided into four levels [Davis 1985].

- **Strategic Planning:** This level involves management of organizational resources, setting the organizational mission, goals and objectives, and monitoring performance against these set targets. At this level, managers look at a construction project as a business profit center and monitor project progress in terms of organizational goals and objectives. A company and project financial management system is an example of a strategic planning system.
- **Management Control:** This includes overall management of construction projects without getting into the operational details. This is a higher level of abstraction of project data to achieve project goals.
- **Operational control:** This is an actual activity level management of a construction project. This requires an information system, which can help in managing day-to-day operations at the construction site. Information subsystems such as job costing, scheduling and contract administration are some examples of subsystems required for operational control.
- **Transactional Processing:** This captures and processes data about construction operations. It includes actual data acquisition such as time cards, activity progress, payroll and accounting data.

All subsystems involved in construction management as described in section 3.2 can be classified in terms of functional and managerial activity subsystems. Table 3.2 shows the position of various subsystems in terms of managerial and functional subsystems. The rows in this matrix represent managerial activities while the columns represent functions of subsystems.

Table 3.2 Functional and Managerial Activity Subsystem Matrix

	Time Planning and Control	Cost Planning and Control	Administration	Resource Management
Strategic Planning	Time bound growth planning	Organizational cost planning	Safety, quality and procedural standards	Organizational financial management
Management Control	Milestone schedule	Estimation and cost control	Contract administration	Project financial management
Operational Control	Detailed schedule	Job-Costing and cost engineering	Contract administration	Accounting and payroll, material management, equipment management, human resource management
Transactional Processing	Progress entry	Resource consumption entry	Document data entry	Data entry for operating systems

This matrix can be used to identify the required subsystems for a particular **type** of organization. For example, a management team headed by a **construction** management organization is most interested in management control and some amount of operational control. Whereas, specialty contractors are more interested in operational control. Therefore, we can use the matrix shown in **table 3.2** to identify functional and managerial subsystems used by different **organizations**. Some examples of applications are:

- A CM firm would use a scheduling system which can plan and control progress at the milestone level and get the detailed schedule from specialty contractors

- A CM firm would use a cost control system which can develop a budget and monitor costs at the level of cost centers, and use job-costing and cost engineering data from specialty contractors.
- A CM firm would use a contract administration system to control contract documents and contract change documents, and make specialty firms use and share the same type of data.
- A CM firm would use a project financial system to control cash flow and for financial management of project costs and funding. The specialty contractor would be interested more in detailed accounting data.

3.3.4 Hybrid Classification

Construction management information subsystems can also be classified as a combination of users using these subsystems, technologies used for these subsystems, and the managerial purpose of these subsystems. Table 3.3 describes these different types of subsystems. The second column describes the functions of these subsystems. The third column elaborates the subsystems giving examples from the construction industry, and the last column demonstrates how time management systems include all types of hybrid system classifications [Modified from Whitten et al. 1998].

Table 3.3 Hybrid Classification of Construction Information Subsystems

[Modified from Whitten et al. 1998].

	Activities	Application in Construction Management	Time Management Application
Transaction Processing System	Captures and processes data about business transactions	Invoices, purchase orders, time cards	Capturing actual progress of an activity
Management Information System	Provides management oriented reporting, usually in a predetermined format.	Weekly consumption reports, monthly accounting reports	Periodic cash flow and progress report
Decision Support System	Provides users with decision oriented information whenever decision making situations arise	Job costing report to identify variations with expected consumption of resources.	Custom report to identify the person responsible for progress delay.
Expert System	Captures the knowledge and expertise of the expert and uses it in decision making	Forecasting productivity of crews on the basis of various project parameters	Forecasting activity duration on the basis of project parameters
Office Automation System	Supports a wide range of business office activities which improves communication between project participants	Electronic mail, Imaging technology for digitizing plans and specifications	Progress updating using electronic mail.
Personal and Workgroup Information System	Designed to meet needs of a single user of a group sharing common interest.	Project level intranet	All the project participants can have access to the schedule data over the project level intranet

3.4 People involved in Information System Development

After identifying the subsystems of a construction management information system, there is a need to focus on the people involved in development and application of such an information system. Information systems are developed essentially to achieve organizational goals by making people working for an organization more productive. Therefore, whenever an information system is developed, different people look into different aspects of the information system. All these people give different suggestions for the information system, and it's a system analyst's role to develop a system which satisfies all system requirements. All these stakeholders in the system can be broadly classified into four categories [Whitten et al. 1998]: System owner, users, designers & builders

1. **System Owners:** This can be a single person or a management team. System owners sponsor a system development project and hence control the time and cost of a project. System owners are least interested in the technical side of system development process. System owners are chief advocates of the system and need to justify requirements to higher management. Examples of system owners are senior project managers, or program directors, or project managers who are in charge of the whole construction project in the case of a small project. Any system development project can start only after the system owner's permission and approval, and after the system owner becomes a sponsor for such a project.

2. System Users: System users are always very close to the system because they frequently use the system. They define the problem to be solved; opportunities to be exploited; requirements to be fulfilled; and business constraints to be imposed. System users know most about the system and are the biggest source of system information. They can be subdivided into internal users and external users.

A. Internal Users: This category includes all employees of the business for which the information system is developed. Good examples of internal users are project managers and project engineers who actually use an information system such as time and cost control. Some internal users function from geographically separate locations but still use the same information system. They are of two types: remote users & mobile users

Remote users use information system from geographically separate static locations. A project office supporting different locations for an information system is an example of remote users. In this case, all project managers of individual projects would access data from the information system at their own project office.

Mobile users work from different mobile locations and share the same information system. This type of user is common in construction management firms where company executives travel around the country selling CM services to clients and using project information on the internet. Members of a virtual team supporting more than one project at a time are also an example of remote users.

B External Users: These users don't work for the organization for which the information system is developed. If an information system developed for a construction management firm is accessed by architects, owners, general contractors and subcontractors for contract administration communication, then they become external users for the information systems. These users usually influence the system development work.

3. System Designers: They translate users' business requirements and constraints into technical solutions. The system designer is responsible for identifying technological solutions, designing networks, databases, user interfaces and reports.

4. System Builders: They construct the information system components based on the design specifications. System designers and builders can be external consultants or members of an in-house IT department.

For most cases in the construction industry the same person performs the functions of both system designer and system builder. The person known as a systems analyst performs the task of system analysis. A systems analyst works from a corporate office to support their information system requirements. A systems analyst facilitates system development and works with people from the business and technology sides. In ideal conditions, the systems analyst identifies system requirements from system owners and users, and then works with the system designers and builders in constructing an actual information system.

3.5 Information System (IS) Architecture

An information system architecture presents a framework for defining all types of information systems and their contents. An information system is made up of four distinct building blocks. These are data, process, interface and geography. The data aspect of IS is managed by database technology, the process part by software technology, the interface by interface technology, and geography by the networking technology. Any information system can be defined in terms of these four building blocks. Each user of information systems as defined earlier has a different focus on these building blocks of information systems. Table 3.4 shows the information system framework and different users' perspectives of an information system [Whitten et al. 1998]. The following section shows the different system focuses and users' perspectives of those system building blocks.

3.5.1 IS Building Block: DATA

Data represent core content of a business, and are managed by database technology. Data are in various different formats in the construction industry due to their complex nature. Some examples of construction industry data are construction material items, their prices, suppliers, the total value of the purchase, and the percentage of work completed.

Table 3.4 Matrix of System Building Blocks and Information System

Workers [Whitten et al. 1998].

Users	Data Focus	Process Focus	Interface Focus	Geography Focus
System Owner	Business Subjects	Business Functions	System Context	Operating Locations
System Users	Data Requirements	Business Process	Interface Requirements	Communication Requirements
System Designer	Database Scheme	Application Schema	Interface Schema	Network Schema
System Builder	Database Programs	Application Programs	Component Programs	Networking Programs
Technology	Database Technology	Software Technology	Interface Technology	Networking Technology

Most of the time system owners are not interested in core construction data; but rather in the business resources and managing data about system resources. System owners are interested at a higher level of abstraction where data can be processed to generate information. Therefore, system owners help in identifying business entities such as contracts, change orders, schedule of values, and relationships between them.

System users capture, store, process and use most of the data. So they know most about the format in which data are edited, processed and stored. System users supply information about different data attributes and formats, and sometimes also add some entities and relationships. For example, different fields required for capturing complete work such as actual start, actual finish, early start early finish, remaining duration, and percent complete are provided by the system users.

System designers convert a data model, which represents the user's view of data relationship, into a database structure which can be implemented by system builders using selected technology. System designers develop "database schema" in terms of a selected database platform. On the basis of this database schema, a system builder develops a database.

3.5.2 IS Building Block: Processes

Processes represent the functions and activities that take place in achieving business objectives. These processes are managed by software technology.

Most of the time system owners are interested in business functions rather than the actual tasks involved in them. System owners can identify different required functions of a system and the expected results. Time control, cost control, and contract administration are some examples of system functions.

System users know most about the details of "business processes" and the policies and procedures underlying those business processes. System users add most of the information about procedures and process models, and work flow models can be used to express business processes in nontechnical, strictly business terms.

System designers convert system users' views expressed in data flow models to technology dependant "application schema". This conversion includes decisions about which processes to automate, how to automate them, and which technology to be used for automation. System builders represent processes

using application developing language that describes inputs, outputs, logic and control.

3.5.3 IS Building Block: Interface

The interface part of information systems includes an effective and efficient interface to the system users and to other information systems. These other information systems can be within the business or with other outside business organizations. Interfaces become crucial in the case of computer-integrated construction management systems where common data are shared using interfaces between different subsystems. Data and processes utilized to share information by cost estimating and progress planning software during the project planning phase are a good example of system interfaces.

System owners are usually interested in the "Big Picture". System owners are interested in internal and external business units, external information systems, and users which have an interface with the system. System owners look into the inputs and outputs related to these interfaces, as well as any government or corporate policies about interfaces. For example, senior project managers of a construction management firm may be interested in identifying the interface of a contract management system with information systems of different contractors, and owners.

System users actually work with a system and, therefore, give specifications about user interfaces, input forms and output reports. For example, the users provide the data entry format with which they are most comfortable for

feeding in percentage completion of work. System users also give specifications for tabular or graphical reports.

System designers design user screens on the basis of users' requirements. This process includes designing graphical user interfaces, screen-to-screen movement and help screens which can result in the most efficient user movements in the application. They also design interfaces between systems such as scheduling and estimating systems where some custom programming needs to be done to match the data format. System builders construct, install, test, and implement both user interfaces and system interfaces.

3.5.4 IS Building Block: Geography

Geography refers to the distribution of data, processes and interfaces to appropriate business locations, and movement of data and information between these locations. Geography becomes a major backbone of an information system when users are at different locations. Networking technology is used to solve problems related to geographic distribution of data and information. Considering geographic distribution of construction projects, networking provides a major link of communication, and tries to solve most of the communication problems. In a construction scenario where a number of remote sites are supported by one job office, networking between these locations becomes a key to communication with different locations. Along with Local Area Networks (LAN) and Wide Area Networks (WAN), internet and project level intranets are developed to improve communication between system users. Even in project offices, a number of users

such as project managers and project engineers, share the same database, and the implementation of such a system depends on successful LAN implementation.

System owners are mainly interested in the operating locations and connecting business partners. System owners also look into data access from these locations, system security and external users.

System users give more detailed information about locations, workstation positions, and data processing and interface requirements. More importantly, system users define communication requirements at different locations.

On the basis of communication requirements defined by users, system designers develop a network schema which includes computer centers, computers, and networking hardware that will be involved in a computer network. This design is based on user communication requirements and a networking technology selection. On the basis of the network schema, system builders develop networks using physical networking elements such as cables, network operating systems, network interface cards, and networking programs to manage the data flow over networks.

Table 3.5 shows the roles of system owners and users in development of cost control systems for an owner's management team. A project owner uses a cost control system to monitor the overall performance of a project in terms of cost. The actual expenses are compared with the work performed and changes in the scope of a project are compared with the initial budget.

Table 3.5 Owner and User Perspectives of Cost Control System

	Data	Process	Interface	Geography
System Owner	Identify entities such as contracts, purchase orders, change orders, requisitions	Functions such as change order management, requisition payment, cost distribution and analysis	Identification of different project managers, external entities such as trade contractors and architects who may access the system. Also interface of scheduling system for scheduling information	Access to for project manager, possible access to job site, owner, architects, and contractors.
System User	Details about each Entity such as requisition calculations, payment options, % tax, approving procedure	Actual activities involved in each process such as acceptance of requisitions, checking amounts, calculating payment, and certifying requisitions.	Input screen details such as contract data entry screen, output reports such as variance analysis reports, format in which scheduling information such as percentage complete of activity accepted in cost control system	Details access at different levels such as data entry from job sites, change order processing from contractors and reporting to owner.

This example elaborates the role of a system owner and users in system development. Roles of designers and builders are not included in this table because they are highly dependent on the application architecture selected for the development of each system.

3.6 System Initiation Process

Since details about system users and building blocks of an information system have been presented, the following sections describe the process of system initiation.

3.6.1 Reason for System Development

As discussed earlier, information systems are used for various functions and they are developed primarily when users feel a need for it. The motivation for system origination is always a combination of problems, opportunities, or a directive [Whitten et al. 1998].

Problems cause an undesirable situation, which prevents organizations from achieving organizational purposes, goals and objectives. For example, if project managers start spending excess time in sending letters, then that problem has to be solved by developing an automated system which can get addresses from the central database and send memos electronically.

An opportunity is a chance to improve organization events even in the absence of specific problems. Developing an organizational level internet that

can be used to communicate between central offices, regional offices and job sites for better organizational communication is an example of system development for a technology-led opportunity.

A directive is a new requirement imposed by company management, government regulations, or some other external influence. For example, If a project owner asks for better transparency with the project data, then a networking project can be initiated to connect the owner directly to a project server so that the owner can get access to the project data. Access to project data can improve transparency between the construction management firm and construction project owner.

Some reasons for initiation of an information system project are as follows:

- Current system can not cope
- Cost saving
- Better service to external users
- Better internal information for decision making
- External forces
- The opportunity provided by new technology
- High technology image

3.6.2 System Development Project Selection

In a large organization with various functional departments and users, numerous system requirements are generated every day. All of these requirements need to be screened and prioritized to see which ones are most critical for the business

functioning. System development projects are initiated according to those requirements and priorities [Davis et al. 1985]

This activity of planning and controlling of computer system development is done by an Information System Steering Committee. The size and membership of this committee depend on the size of the organization and its computer applications. The following activities are usually performed by a steering committee [Curtis 1995].

- To recommend an overall business focus strategic policy for information system development.
- To ensure that individual department information needs are being satisfied. This is where the user's requests are initiated and transferred for approval to the committee.
- To screen, prioritize, initiate and monitor individual projects. This process includes formation of a project team, and developing the project scope and budget.
- To coordinate individual projects to improve general coordination
- To report progress of various systems projects "upward" to top management.

All the systems initiated can be classified as planned system initiation and unplanned system initiation. When system owners, users, or system analysts initiate a project, it is called unplanned system initiation. Unplanned system initiation gets lower preference over a planned system initiation that is a result of one of the following projects.

1. **An Information Strategy Planning Project:** This project results in an information strategy plan that has examined the core business of an organization as a whole to identify those systems and application development projects that will return the greatest strategic value to the business. Information system development for a new construction project during the mobilization phase is an example of a strategically identified information systems project.

2. **Business Process Redesign Project:** A business process redesign project thoroughly analyzes a series of fundamental business processes to eliminate redundancy, bureaucracy and to improve efficiency. The next step in this project is to redesign an information system for those business processes. If an organization finds that the process of handling change orders is very long and time consuming, and decides to improve the process, then appropriate modifications need to be done in the information system, which supports the change order process.

3.6.3 System Development Instances in Construction

In a construction environment, all the instances of system development can be classified into the following three scenarios.

1. **New Construction Project:** Every project has its specific requirements on the basis of project plans, specifications and management. Therefore, the information system development process starts along with the mobilization process, and normally takes one to two months for development. This project is initiated by the senior project manager or project director who is responsible for

the performance of the project and who acts as a system owner. Project managers, site engineers, schedulers, and contract engineers act as system users. This system is normally set in the project office with access from different project locations.

2. New Organizational System: Construction organizations usually use different project planning and control software, which support more than one project. A number of strategic decisions needs to be taken while selecting software products and designing information systems. Typical functional information subsystems which become part of a corporate information system are designing, cost estimating, progress planning and controlling, job costing and accounting.

3. Modification of an Existing Information System: These projects can be at the organizational level or project level. The main reason for these modification projects is the changing system requirements from the system users and owners, or inefficiency of an existing information system. This inefficiency can happen due to changes in project environment or external requirements such as an owner asking for reports which the present system is not capable of generating. Different issues such as customization, reengineering or system integration may be involved in these system development projects.

3.7 Summary

This chapter is aimed at explaining the information system development environment, the basic contents or building blocks of information systems, and who is involved in developing and using information systems in the construction industry. Along with the description of generic theory of information systems, this chapter gives a construction management perspective of a system development environment and the importance of information systems to the construction industry. This chapter also presents the different types of construction management systems and their classification. These classifications can be utilized to identify the required construction management information system for a particular type of organization. At the end, this chapter describes the reason for new system development and provides examples of such instances in construction industry. The next chapter is aimed at defining a structured methodology for developing information systems in a construction project environment.

CHAPTER 4

SYSTEM DEVELOPMENT METHODOLOGY FOR CONSTRUCTION PROJECT MANAGEMENT ENVIRONMENT

4.1 Introduction

After describing the information system environment in general and for construction management in particular, there is a need to concentrate on the information system development process. Information systems are a product similar to a building, highway or dam. Therefore, development of an information system follows same steps as any other project development. The basic steps in project development are planing, analyzing, designing, constructing and supporting. The information system development process also follows these processes and uses project and process management techniques to plan, monitor and control the system development process. Figure 4.1 shows the process of project development. The boxes show the phases involved in project development, whereas the arrows show the precedence relationship between them.

As explained in the previous chapter, the system development process becomes very complex and complicated due to the number of people involved and the interaction between them, as well as the large amount of data and process management, technology selection, and technology management involved in system development.

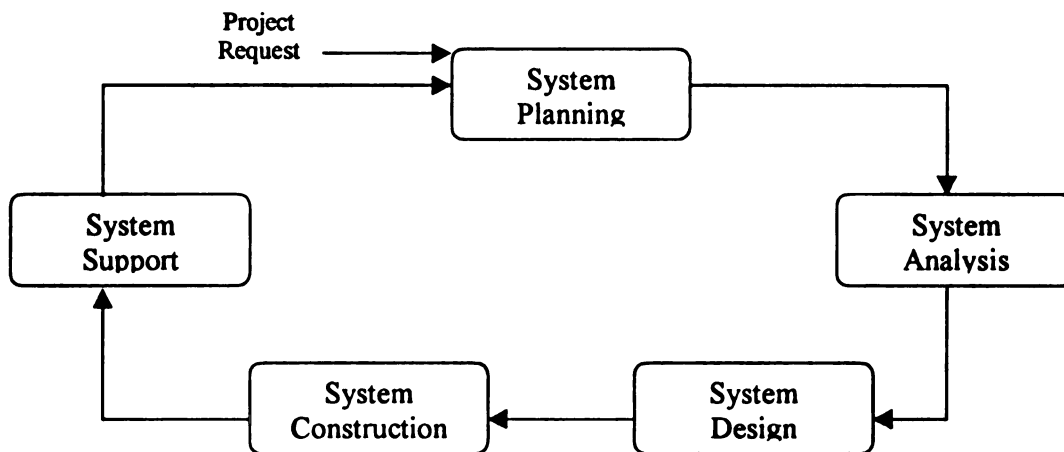


Figure 4.1 System Development Process

Therefore, system developers need to use structured development methods or methodologies which can guide them in the system development process. This chapter focuses on the different components of methodology, selection processes and phases, activities, deliverables and tools used for accomplishing system development in a construction environment. This chapter explains the importance of a structured methodology, its components and selection criteria for those components before defining the system development methodology for a construction project management information system.

4.2 Structured System Development Methodology

A system development methodology is a business process used to develop an information system. A methodology consists of three components. The first component is a system development process, which defines the phases, or

groups of activities, which lead to system development. All methodologies are derived from a logical problem solving process that is called a system development life cycle. This life cycle is essentially a project management tool used to plan, execute, monitor and control system development projects. Models of system development life cycle (SDLCs) are used to describe the system development process. The second part of a methodology is the **technique** used to execute phases or groups of activities described in the system development process. These techniques are the "how" of software processes. The third element of methodology is the CASE (computer-aided systems engineering) technique. **CASE tools** are software programs developed to automate some of the phases and activities of structured methodology.

Therefore, one can define methodology as a physical implementation of a logical life cycle that incorporates (1) Step-by-step activities for each phase, (2) Individual and group roles to be played by each activity, (3) deliverables and quality standards for each activity, and (4) tools and techniques to be used by each activity. [Whitten et al. 1998]

Various organizations involved in system development use different methodologies. Some are still using unstructured, "Ad hoc" methods of system development. Most of those methodologies are available in the market which organizations can buy and use in their development efforts. Organizations can even develop an in-house methodology and tailor it to the skills, experiences and requirements of the employees. In any case, organizations need to consider issues related to methodology such as market assessment, selection criteria, and

adoption [Topper et al. 1994]. The following list illustrates some of the reasons for companies to use structured methodologies:

- | | |
|-------------------------------------------------|----------------------------------------------|
| 1. Consistent reproducible approach | 6. Reduced risks associated with |
| which can be applied to all the projects | shortcuts and mistakes |
| 2. Complete and consistent | 7. Standardized deliverables produced |
| documentation from one project to | during development effort. |
| other | |
| 3. Efficient maintenance | 8. Project measurement |
| 4. Project management | 9. CASE tools support |
| 5. Training | 10. Technique Improvement |

Even with all these advantages, there is still a price tag associated with each of them. In practice, a structured methodology is required for development of complex systems consisting of a number of functional subsystems used by different users interacting with each other to achieve common organizational goals. A structured methodology may not be required in the case of a small business with standard procedures and clearly defined needs.

After initialization of an information system project, the system analyst needs to make decisions about the selection of appropriate paths available within the selected methodology for system development.

4.3 Contents of Structured Methodology

A system development methodology consists of processes, techniques and CASE tools to help in achieving system development goals. Each methodology consists of different variations for different types of project environments. These variations consist of different combinations of processes, techniques and CASE tools. The following section will identify different types of processes, techniques and CASE tools that become part of a methodology and part of its selection criteria.

4.3.1 Selection of System Development Process

Selection of an appropriate system development process depends mainly on the project variables. These project variables are project size, degree of structuredness of the system, user task comprehension and developer task proficiency [Davis 1985].

1. **Project Size:** Normally project size is measured by two components. One is project duration and the other is total cost. Normally projects with a longer duration have more people involved in the system development process. Also, more people get involved in establishment and modification of system requirements, and involvement of additional people results in an increase in volume and complexity of communication. There is also a higher possibility of changes in users and developers involved during the system development.
2. **Degree of Structuredness:** This variable refers to the relative amount of structuredness for the decisions to be taken using an information system. Due to the lack of structuredness, there exists an uncertainty about the initial

requirements and alterations of those requirements. A system with more structuredness results in better capturing of user requirements without further changes in those requirements.

3. **User Task Comprehension:** This variable refers to the user's comprehension of the tasks expected to be performed by the information system. If users have better understanding of the tasks expected to be performed by an information system, then the level of uncertainty about initial requirements and modifications is reduced considerably.

4. **Developer Task Proficiency:** This variable refers to the degree of certainty with which the developer will be able to understand requirements accurately and completely and develop an application to achieve them. This proficiency depends on the training and experience of the system development team for a particular type of project.

Based on these factors, the selection of a system development process can be divided into two parts.

1. Determine the level of development uncertainty
2. Select a system development process suitable for the observed level of uncertainty.

4.3.2 System Development Processes

Based on the uncertainty involved in system development, the following four processes are identified as suitable for a particular class of projects. Again different authors and researchers have identified different versions or variations of

these development processes, but the primary concept remains the same
[Modified from Davis 1985, Yorden 1989]

1. **The Classical Project Life Cycle:** The user statements of requirements are accepted as complete, correct and firm, and the system is based on those requirements. It consists of the main phases of system development such as survey, analysis, design and construction, which take place one after another. No changes are done in requirements in later part of the system development and no procedures are used to gain assurance about the correctness of initial requirements. This process is used for small projects with a high degree of structuredness, a high level of user understanding of the system, and experienced system developers. This method adds to greater user responsibility and to increases in development efficiency.

2. **Structured Project Life Cycle:** Also called the waterfall life cycle, this is the most formal traditional system development process, which is most widely accepted and practiced. Figure 4.2 shows the waterfall model of system development. The boxes show the phases involved in system development whereas the arrows show the precedence relationships between these phases. It proceeds from requirements to the final development phase in a top-down manner without many changes in initial requirements. Each phase culminates in a document, which becomes the basis of the next phase. Normally, only one activity or phase takes place at a given time during the development. An assurance procedure is used to ratify conformance with the requirements after every phase. This method is used for a medium size structured system with very high user task

comprehensiveness and high developer task proficiency. Some of the basic deficiencies of this model are long feedback cycles, high level of rigidity, very unrealistic flow, bottoms-up testing and no variation in levels of abstraction.

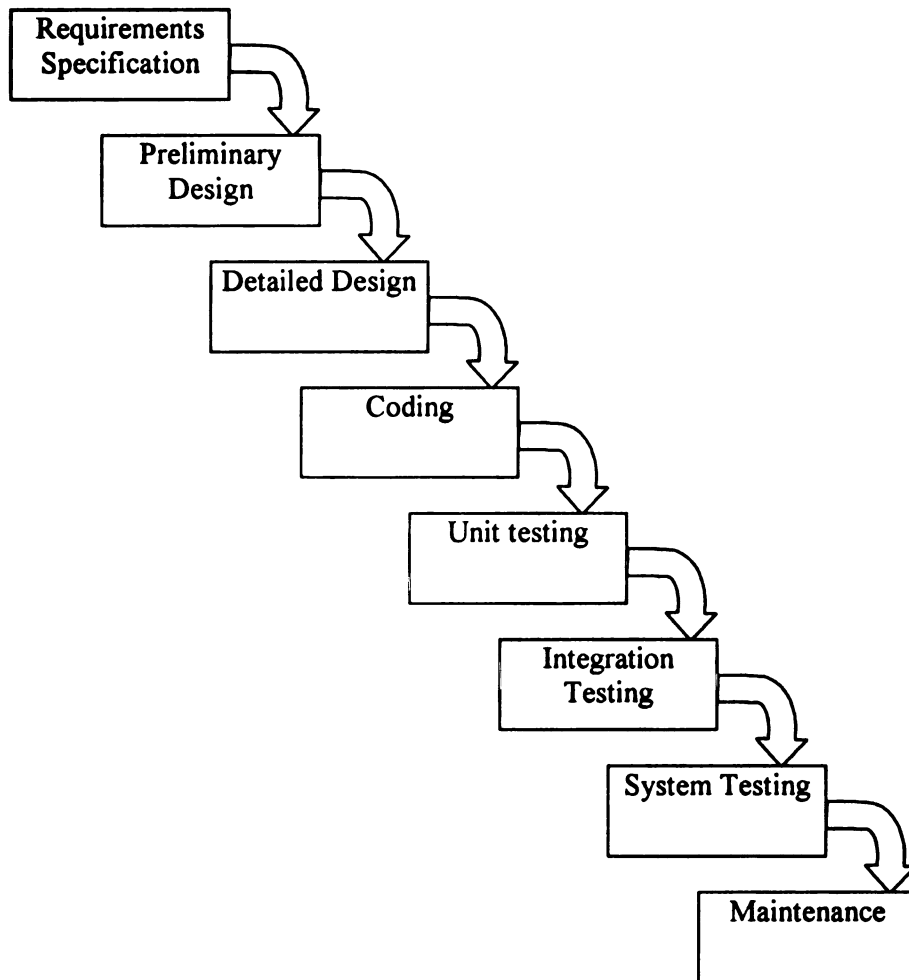


Figure 4.2 Waterfall Life Cycle Model [Topper et al. 1984]

3. **Iterative Structured Project Life Cycle:** In the case of high requirement uncertainty, iteration is added to the structured project life cycle. In this process, requirements are changed during the development stages and, therefore, developers have to go back and work on the requirement gathering phase. Hence, a number of activities may take place simultaneously. This method is normally used in the case of large multi-user systems where application areas are new to the users and developing organizations.

4. **The Prototyping Life Cycle:** In the case of extreme uncertainties where users are not able to state requirements without having a look at the developed system, a prototype system is developed and then user feedback is collected to get better requirements for the system. Such a method is also called an experimental assurance process. This method is utilized in the case of an unstructured system used by multiple users without system task comprehension. Decision support systems developed for upper management are an example of a type of system which uses a prototyping methodology.

Table 4.1 shows the decision-making variables corresponding to different system development processes. In this table, different system development processes are shown as rows and decision-making variables are shown as columns. For example, the system development process, which is a "classical project life cycle" is used for projects with small project size, high degree of structuredness, high task comprehensiveness and high developer task proficiency.

Therefore, one can conclude that this process should be used when overall degree of uncertainty is low.

Table 4.1 System Development Processes and Decision-Making

Parameters

Process	Project Size	Degree of Structured ness	User Task Compre hension	Developer Task Proficiency	Uncertainty
Classical Project Life Cycle	Small	High	High	High	Low
Structured Project Life Cycle	Medium	High	High	High	Medium
Iterative Structured Project Life Cycle	Large	Medium	Medium	Low	High
Prototyping Life Cycle	Medium -Large	Low	Low	High	Extreme

4.3.3 System Development Techniques/ strategies

As described earlier, techniques are the "how" of a system development process. The system analyst needs to select a technique after identifying the process of system development. Techniques make use of notations and diagramming tools for modeling, specifying, and designing an information system and these programs or specifications become the representation of the system. Different techniques have different orientations and they emphasize different parts of a system. The following list includes the most dominant techniques used in the industry [Topper et al. 1994].

- 1. Modern structured analysis** (a function-oriented technique) stresses the processing or functionality of an information system. Typically, in these techniques, processes are defined first and data follow these processes.
- 2. Data-oriented** techniques accent the data component of a system. Typically in these techniques, data are defined first and then the processes.
- 3. Control-oriented** techniques are an extension of process-oriented techniques that focus on the control behavior of a system.
- 4. Information Engineering** (Information-oriented system) is a data-centered, but a process sensitive technique that is applied to the organizations as a whole. It includes high level data and process models, and the integration of application via these models.
- 5. Object-oriented** techniques feature the integration of data and the valid processing (encapsulation) of that data into a construct called an object. These are the newest approaches and they attempt to address some inadequacies of earlier techniques.
- 6. Prototyping** techniques underscore the use of system simulation prior to building and maintaining an information system. System developers should still use the model driven techniques for developing prototypes.

Along with these techniques which are associated with application development projects, there are techniques such as Information engineering which can be applied to strategic information system projects and business process redesign for redesign of business processes. Some techniques are a combination of the above

mentioned techniques such as **joint application development (JAD)** which combines the model-based technique and the prototyping technique to bring together system owners, users, analysts and builders to jointly define and design systems. Some developers are extending the prototyping technique along with JAD and model based techniques to perform "**rapid application development (RAD)**"

All the above mentioned techniques were originally created by an individual or group of individuals, and many techniques are often identified with the people who created them. These techniques are often viewed as competing alternatives, but in reality certain combinations complement each other. The application and selection of a particular technique depends on the development environment. A developer can adopt a commercially successful technique and then tailor it to the way organizations already develop systems.

4.3.4 CASE (Computer-Aided Systems Engineering) Tools

CASE is an application of information technology to systems development activities, techniques and methodology. CASE tools are programs that automate or support one or more phases of a system development life cycle. The technology is intended to accelerate the process of developing information systems and to improve the quality of the resulting system. It is an enabling technology that supports a methodology's preferred strategies, techniques, and deliverables.

CASE tools can be classified on the basis of life cycle phases that they support. The tools that automate or support upper or earlier phases of system

development such as survey, study, definition, and design phases, are called **upper-CASE**. Similarly, the tools that automate or support lower or later phases of system development such as detailed design, construction and delivery are called **lower-CASE**. The center of a CASE tool's architecture is a database called a **repository**. A **CASE repository** is a database where developers can store diagrams, descriptions, specifications, and other by-products of system development. A repository can be formed at different levels such as one for the whole organization where all system documentation can be stored for all projects that used CASE tools. Another repository can be formed at the workgroup level where a project team can share the repository and transfer information back and forth between the corporate and workgroup repository. CASE tools normally provide some of the following facilities:

1. **Diagramming:** Helps to draw system models
2. **Description tools:** Help to managing non-graphic documentation.
3. **Prototyping:** Helps to create system components such as inputs, outputs and programs
4. **Inquiry and reporting:** Help to extract models, description, and specifications from the repository
5. **Quality management:** Helps to assess models, descriptions and prototypes for consistency, completeness, or conformance with accepted methodologies.
6. **Other facilities** include decision support tools, documentation organization methods, code generators, design generation, code generator, testing tools, data sharing tools, version control tools, and housekeeping tools.

Some of the most commonly cited benefits from using CASE tools include improved productivity, improved quality, better documentation, and reduced lifetime maintenance. All methodologies do not require CASE but most of the methodologies do benefit from CASE tools and do recommend CASE tools. After identifying the different components of methodology, the following section identifies the core methodology applicable in a construction project environment.

4.4 Construction Management System Development Methodology (CMSDM):

CMSDM defines the system development methodology for developing construction management information systems in a construction project environment. There are two possibilities for system development in a project environment. The first is developing information systems for a new construction project, and the second is replacing existing non-performing information systems. As discussed earlier, before defining a methodology there is a need to identify the processes, techniques and CASE tools that should be used as a part of that methodology.

4.4.1 Construction Project Variables

Before developing a structured methodology for developing an information system in a construction project environment, one needs to analyze the project environment to identify the processes, techniques and CASE tools that can become part of the methodology. Again, it is very difficult to generalize any project

characteristic due to the diverse nature of construction projects. But even in that case, some characteristics are observed as common among all construction projects.

Investment in system development takes place in almost all types of construction projects. In most of the construction projects, a significantly high number of organizations are involved, and they generate a huge amount of data and information. Generally, in a construction project all processes related to project control are defined according to the organizational manuals and in consultation with the owner, architects, contractors, and CM firm. Therefore, one can conclude that the information systems developed are quite structured in their format. Considering the emergence of systems development in the construction industry, the developers are not very experienced with the system development process. The users are very knowledgeable about system processes, but also very conservative about the possible changes in their performance. Also, they may know the system very well but may not be able to explain the requirements.

Based on all of these variables related to the system development process selection, one can conclude that the development environment consists of a high degree of uncertainty. In such an environment, the selected methodology should use an iterative structured system development life cycle using prototyping for the analysis and design phases. Again this conclusion is based on the majority of construction projects where significant investment is made in the development of an information system.

4.4.2 Construction Project Environment

The system development environment in the case of new construction projects depends on the client of the information system. The project's client can be an owner, CM firm or contractor. The role of people involved in the information system development changes according to the project size, type of project, organizational structure, and management style of the client organization. As described in section 3.4, the senior project manager or project director who is responsible for the overall performance of a construction project always acts as a system owner. A user manager, known as the project controls manager heads the system user team. This person acts as a coordinator between system developers and users. All other positions such as scheduler, contract engineer and project managers act as system users. Figure 4.3 shows the organizational structure for a system client [modified from Barrie & Paulson, 1995]. In the case of small projects, a project manager becomes the system owner as well as a system user along with project engineers, and the contract expediter becomes the main system manager.

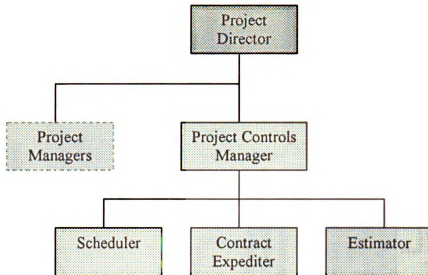
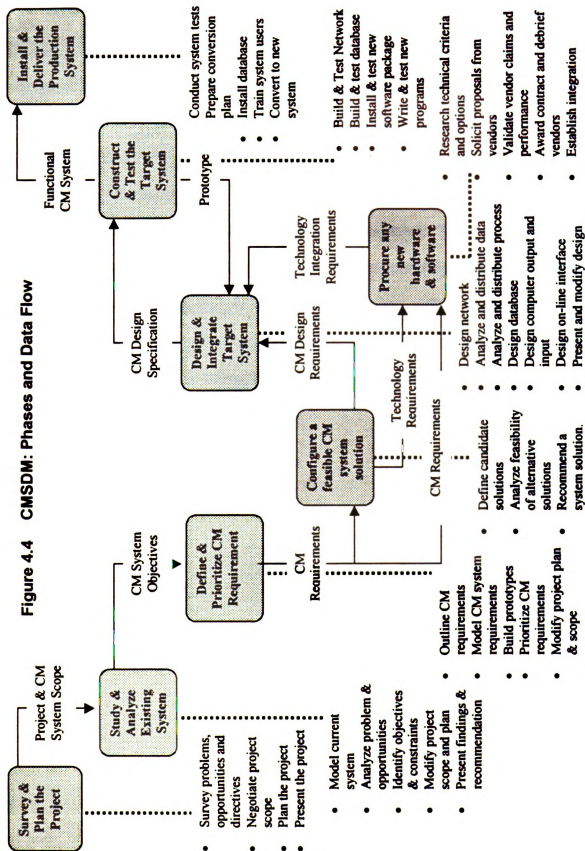


Figure 4.3 Project Organizational Structure

4.4.3 CMSDM: Phases and activities

Construction Management System Development Methodology (CMSDM) does not impose a single process or technique or CASE tool on a system developer. This methodology integrates all of the popular techniques including structured analysis for process modeling, information engineering via data modeling, prototyping via rapid application development, and joint application development for all methods. It is very much influenced by the project characteristics of the construction industry. Considering the different project characteristic and system parameters, system analysts need to make appropriate changes to this generic methodology. Figure 4.4 shows the system development phases and the data flow between them. The boxes in figure 4.4 represent the phases and arrows represent the data flow between them. The dotted lines connect the phases and the activities involved in individual phases.



Each phase in CMSDM consists of multiple activities, and each activity in this methodology is divided into four sections. The first section explains the purpose of each activity. The second section explains the inputs, processes and deliverables of each activity. The third section includes examples applicable from the construction industry which relate some of these activities to the construction environment. The fourth section identifies the possible variations of the same activities with respect to project and system variables. The primary system variables are number of system users, use of commercially available software solutions or custom solutions, or use of built-in report writer or external report writer. The basic project variables are project origination and the urgency of a project. These variables are explained in detail in section 4.5.

4.4.3.1 Survey Phase

This is the first phase of the system development life cycle. It is mainly focused on identifying problems, defining the system's scope of the system, developing the project team, and planning the system development project regarding project budget and cost. The project director and system analysts are involved in all activities of this phase. Fact-finding techniques such as interviewing are used in this phase. The following sections describe the activities involves in the study phase along with an example from the construction project management field related to each activity. Figure 4.5 shows the deliverables generated from each activity and the relationships between these deliverables.

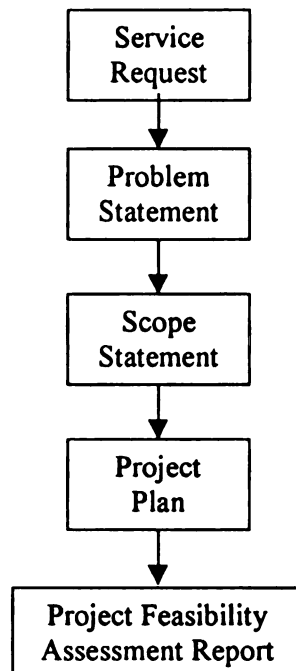


Figure. 4.5 Survey Phase of CMSDM

4.4.3.1.1 Survey problems, opportunities, and directives

Purpose: The purpose of this activity is to quickly survey and evaluate each identified problem, opportunity, and directive with respect to urgency, visibility, tangible benefits, and priority.

Inputs/ Process/ Deliverables: Generally, a project director or project manager, who is ultimately responsible for the performance of the project, initiates the system with a request for system service. This request is converted into a problem statement which lists all problems, opportunities and directives in terms of urgency, visibility and tangible benefits. Based on these factors all items in a system request are prioritized and possible solutions are identified.

CM Example: Ideally, after signing the contract, a project director identifies the system development requirements such as the time and cost monitoring system and the contract administration system. Based on these requirements, a system request is generated which lists all system requirements. System analysts working out of a regional office handle the job of system development. It is always preferable to employ a system analyst from within the organization, as that person is knowledgeable about the organizational procedures and can be used during the support phases. The system analyst converts this system request into a *problem statement*.

Variations: All types of projects need to go through this activity.

4.4.3.1.2 Negotiate Project scope

Purpose: The purpose of this activity is to define the boundary of the system and project. The boundary should be defined as precisely as possible to minimize the impact of a creeping scope. The project's scope may increase in the future but the budget and schedule should also be changed according to any changes in scope.

Inputs/ Process/ Deliverables: Based on the *system request* and *problem statement*, a *scope statement* is developed. The scope statement consists of the following four components that correspond to four building blocks.

- **Business Subjects:** List of data elements about which the system needs to provide information
- **Business Function:** List of business functions that would be included in or affected by this system
- **System Context:** List of external people, organization units, organizations, or other systems with which the system might have to interact.
- **Operating Location:** List of specific business operating locations that will be included within the scope of the project.

The system scope is developed after discussing the proposed solution for each item in a problem statement with the project director. The project scope is defined in terms of a list.

CM Example: The scope statement might include:

- **Business subjects** such as contracts, purchase orders, and change orders
- **Business Functions** such as approving change orders

- System context such as sharing "percent activity complete" data between scheduling and contract administration system
- Operating locations such as job office and site office.

Variations: All types of projects need to go through this activity.

4.4.3.1.3 Plan the Project

Purpose: The purpose of this activity is to develop the initial project schedule and resource assignments.

Inputs/ Process/ Deliverables: Based on the initial two activities, project costs and time are estimated and the project budget and schedule are developed. This schedule and budget are negotiated with the project director and finalized. A project schedule developed at this point should consist of the main system development phases. A detailed schedule may be developed for the next phase. Considering the project environment, a system analyst has to decide which variation of the system development methodology is most applicable to the project environment. Also, a project team is identified and specific roles are assigned to the people. Henceforth, the whole team works as a group to achieve the system's goals. Figure 4.6 shows the detailed schedule of the activities and phases involved in CMSDM in bar chart format.

CM Example: The system analyst negotiates and finalizes the project budget and schedule with the project director. This schedule should be consistent with the start of the construction phase of the project, and the budget should be consistent with the budget of the whole construction project. The project plan may also include

different parts of an information system based on system priorities. For example, development of a project intranet will be considered as a second phase of the system development project.

Variations: This activity can be expedited in case of urgent system requests.

4.4.3.1.4 Present the Project

Purpose: The purpose of this activity is to communicate the project and its goals to all staff members, and to secure any required approval to continue the project.

Inputs/ Process/ Deliverables: A *Project Feasibility Assessment Report* is developed using all inputs to the previous activities. This report acts as a internal contract between the system analyst and the project owner. This report may also be presented to the project support group working out of the regional office to communicate the progress of the system development project. This report may also be communicated to all concerned parties in order to develop transparency and coordination.

Variations: This activity can be expedited in case of urgent system requests.

Activity Description	Orig Dur	Early Start	Early Finish	1997 DEC 29	1998 JAN 5	JAN 12	JAN 19	JAN 26	FEB 2	FEB 9	FEB 16	23
System Development Project												
System Analysis												
Survey and Plan the project												
Survey problem and opportunities	1	01JAN98	01JAN98									
Negotiate project scope	1	01JAN98	01JAN98									
Plan the project	1	02JAN98	02JAN98									
Present the project	1	05JAN98	05JAN98									
Feasibility document	0		05JAN98									
Study and Analyze the Current System												
Model the current system	2	02JAN98	05JAN98									
Analyze Problems and Opportunities	1	06JAN98	06JAN98									
Establish system improvement	1	06JAN98	06JAN98									
Modify project and scope plan	1	07JAN98	07JAN98									
Present the project	1	08JAN98	08JAN98									
Study Report	0		08JAN98									
Define and Prioritize Business Requirements												
Outline business requirements	1	07JAN98	07JAN98									
Model business system requirements	4	07JAN98	12JAN98									
Build discovery prototypes	1	08JAN98	08JAN98									
Prioritize business requirements	1	13JAN98	13JAN98									
Modify project plan and scope	1	13JAN98	13JAN98									
Requirements statement	3		13JAN98									
System Design												
Configure a Feasible Target Solution												
Define candidate solutions	1	14JAN98	14JAN98									
Analyze feasibility of candidate	2	15JAN98	16JAN98									
Recommend a system solution	1	18JAN98	18JAN98									
				<input checked="" type="checkbox"/> Survey problem and opportunities <input checked="" type="checkbox"/> Negotiate project scope <input checked="" type="checkbox"/> Plan the project <input checked="" type="checkbox"/> Present the project <input checked="" type="checkbox"/> Feasibility document <input checked="" type="checkbox"/> Model the current system <input checked="" type="checkbox"/> Analyze Problems and Opportunities <input checked="" type="checkbox"/> Establish system improvement objectives <input checked="" type="checkbox"/> Modify project and scope plan <input checked="" type="checkbox"/> Present the project <input checked="" type="checkbox"/> Study Report <input checked="" type="checkbox"/> Outline business requirements <input checked="" type="checkbox"/> Model business system requirements <input checked="" type="checkbox"/> Build discovery prototypes <input checked="" type="checkbox"/> Prioritize business requirements <input checked="" type="checkbox"/> Modify project plan and scope <input checked="" type="checkbox"/> Requirements statement								
				<input checked="" type="checkbox"/> Define candidate solutions <input checked="" type="checkbox"/> Analyze feasibility of candidate solutions <input checked="" type="checkbox"/> Recommend a system solution								

Figure 4.6 CMSDM: Bar Chart

Activity Description	Orig Dur	Early Start	Early Finish	1997 DEC 29	1998						
					5	12	19 JAN	26	2	9 FEB	23
System recommendation	0		19JAN98				◇	System recommendation			
Design and Integrate the new System											
Design outputs and inputs	4	09JAN98	14JAN98				◇	Design outputs and inputs			
Design Network	1	20JAN98	20JAN98				◇	Design Network			
Analyze and distribute data	1	21JAN98	21JAN98				◇	Analyze and distribute data			
Analyze and distribute processes	1	22JAN98	22JAN98				◇	Analyze and distribute processes			
Design database	2	22JAN98	23JAN98				◇	Design database			
Baseline Design	0		23JAN98				◇	Baseline Design			
Design on-line user interface	2	26JAN98	27JAN98				◇	Design on-line user interface			
Present and review design	1	28JAN98	28JAN98				◇	Present and review design			
System Implementation											
Construct the new System											
Build and test Network	4	23JAN98	28JAN98				◇	Build and test Network			
Build and test database	1	29JAN98	28JAN98				◇	Build and test database			
Install and test software package	1	30JAN98	30JAN98				◇	Install and test software package			
Write and test new programs	2	02FEB98	03FEB98				◇	Write and test new programs			
Version signoff	0		03FEB98				◇	Version signoff			
Deliver the System into Operation											
Conduct the system test	1	04FEB98	04FEB98				◇	Conduct the system test			
Prepare conversion plan	1	05FEB98	05FEB98				◇	Prepare conversion plan			
Install databases	1	05FEB98	05FEB98				◇	Install databases			
Train system users	3	06FEB98	10FEB98				◇	Train system users			
Convert to new system	1	11FEB98	11FEB98				◇	Convert to new system			
Operational system	0		11FEB98				◇	Operational system			

Figure.4.6 CMSDM: Bar Chart (Cont.)

4.4.3.2 Study Phase

The main objective of the study phase is to understand the business processes better. Time spent on this phase depends mainly on the experience of the system developer about the system environment and the unique project requirements. This phase is used to understand the business vocabulary so that a system analyst can have effective communication with the system users. Some modeling techniques are used but detailed models of an existing system are not developed because the real purpose is to understand the existing business processes. The system analysts work with the user managers and the system owner to accomplish these activities. The following sections describe the activities involved in the survey phase along with an example from the construction project management field related to each activity. Figure 4.7 shows the deliverables generated from each activity and the relationships between these deliverables.

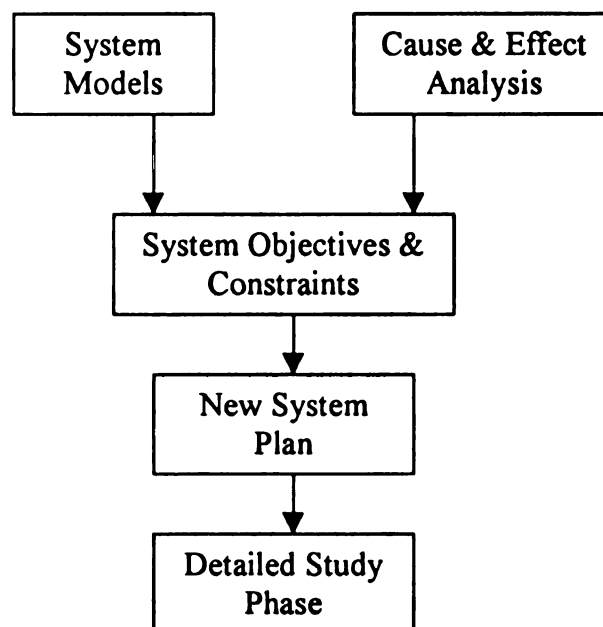


Figure 4.7 Study Phase of CMSDM

4.4.3.2.1 Model the Current Construction Management (CM) System

Purpose: The purpose of this activity is to learn enough about the current system's data, processes, interfaces, and geography to expand the understanding of scope and to establish a common working vocabulary for that scope.

Inputs/ Process/ Deliverables: The principal deliverables of this activity are the system models. The system analyst develops system models by using fact-finding techniques with the user managers, and holding joint application development (JAD) sessions with all key people. Relevant information is also captured through company manuals. This study helps the system analyst to understand the business and processes involved in it. Based on this study, data, process, and interface models are developed. These system models are verified by system users to achieve consensus on the construction management processes.

CM Example: Typically, a system analyst would discuss different data types such as change orders and proposals with the project controls manager to get a better understanding of these data elements. In the case of processes, a system analyst would refer to organizational manuals to understand the processes involved with data elements such as document flow during acceptance of change orders.

Variations: If a system development is triggered by a need to modify the existing project system, then it is essential to model and understand the existing system to make appropriate changes. In the case of a new system, only a generic model needs to be developed which can give a basic idea about the data, processes, and interfaces of the generic construction project control system. Again, this activity

would take much less time if a system developer has had experience in developing this type of system.

4.4.3.2.2 Analyze Problems and Opportunities

Purpose: The purpose of this activity is to understand all underlying causes and effects of all problems and opportunities.

Inputs/ Process/ Deliverables: Based on the problem statement, each problem and opportunity are analyzed strictly in a business sense to identify the causes and effects of those problems and opportunities. This study helps to understand issues related to the problem or opportunity before one can make decisions about solving them. This step is more important in the case of replacing an old information system by a new one.

CM Example: Consider a problem such as a situation where schedules need to be updated and analyzed more frequently but the scheduler is too busy with updating past data in the system.

Variations: While developing a new system, one needs to analyze technology driven opportunities rather than existing problems.

4.4.3.2.3 Establish System Improvement Objects and Constraints

Purpose: The purpose of this activity is to establish criteria against which the developed system can be measured and to identify any constraints that may limit flexibility in achieving those improvements.

Inputs/ Process/ Deliverables: An objective is a measure of success. Objectives should be measurable statements of business performance that define the expectations for the new system. Objectives must be tempered by identifiable constraints. Constraints fall into four categories: schedule, cost, technology and policy. The main deliverables of this activity are system improvement objectives and constraints.

CM Example: A system can have different objectives such as on-line data entry or on-line publishing of reports. The following list illustrates possible constraints for information system development.

- **Schedule:** The system has to be running before the actual construction starts.
- **Cost:** The system has to be within budget. Therefore, all expensive system solutions should be evaluated against this constraint.
- **Technology:** Technical sophistication of organizational staff can be a big constraint before selecting a technology tool.
- **Policy:** All systems should use "MS Project" as scheduling software

Variations: All types of projects need to go through this activity.

4.4.3.2.4 Modify Project Scope and Plan

Purpose: The purpose of this activity is to reevaluate project scope, schedule and expectations. The overall project plan is then adjusted as necessary, and a detailed plan is prepared for the next phase.

Inputs/ Process/ Deliverables: System analysts need to make decisions on the basis of findings in the study phase to determine if the system objectives can be

accomplished within time and budget. Based on this decision, a revised project plan is developed. This revised plan takes all facts about the system, objectives and constraints under consideration and negotiates scope of the system with the system owner. Objectives are also prioritized to identify the higher priority issues.

CM Example: A System analyst may decide to go ahead with a scheduling and cost control system and consider document management as a part of a second phase.

Variations: All types of projects need to go through this activity.

4.4.3.2.5 Present Finding and recommendations

Purpose: The purpose of this activity is to communicate the project plan and goals to all staff members.

Inputs/ Process/ Deliverables: The key deliverables of this activity are *the detailed study findings*. It usually includes a feasibility update, which consists of problems, opportunities, cause-effect analysis, system objectives and constraints, and a revised project plan. This activity helps to communicate to everyone related to the project about the revisions and the new project plan. It also acts as an agreement between the system owner and system analysts. It also helps to document changes and the new scope of the project.

Variations: This activity can be expedited in case of urgent system requests.

4.4.3.3 Definition Phase

The definition phase is used to define the system business requirements in a strictly logical manner. Different modeling techniques are used to represent the system requirements. These models are later used for selecting the application architecture and for designing the system. Examples of models typically used for this purpose will be defined and described in this section. Models identify the user requirements in a logical manner, which helps in identifying and verifying the IT tools as a part of the information system. The following sections describe the activities involved in the definition phase along with an example from the construction project management field related to each activity. Figure 4.8 shows the deliverables generated from each activity and the relationships between these deliverables.

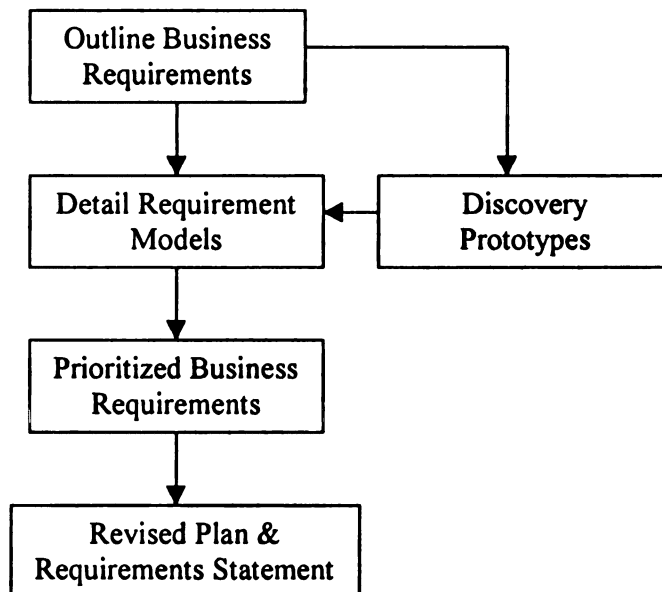


Figure. 4.8 Definition Phase of CMSDM

4.4.3.3.1 Outline CM Requirements

Purpose: The purpose of this activity is to identify, in general terms, the business requirements for a new or improved information system.

Inputs/ Process/ Deliverables: Based on the *system improvement objectives* a *requirement statement outline* is developed. Each objective is associated with the corresponding system input, process and output. This framework acts as a guideline for future activities in the definition phase. A business requirement outline is more of a guideline than an exhaustive list of business requirements. It should be utilized more for organizing the system requirements in a structured manner to make sure that all requirements are covered.

CM Example: System requirements from the different project control subsystems such as cost control and time control can be outlines to make sure that all system requirements are identified at a higher level of abstraction.

Variation: This activity is very essential in the case of developing an integrated system consisting of different applications such as time, cost, and contract monitoring system.

4.4.3.3.2 Model CM System requirements

Purpose: The purpose of this activity is to model business system requirements such that they can be verified by the system users and are subsequently understood and transformed by the system designers into a technical solution.

Inputs/ Process/ Deliverables: Based on the outline of the business requirements, logical models are developed. Logical models depict what a system

must do, and not how the system should be implemented. The deliverables of this activity are the system models. System models are of four types, consistent with the system development building blocks.

Data Models (such as Entity-relationship diagrams) are used to model the data requirements of the new system and the relationships between the different data elements. These data models eventually serve as the starting point for designing a database.

Process Models (such as Data Flow Diagrams) are used to represent the workflow through business systems. These process models serve as a starting point for designing computer applications and programs.

Interface Models (such as context level diagrams) are used to depict net inputs to the system, their sources, net outputs from the system, their destinations, and shared databases. These interface models serve as the basis for designing user and system interfaces.

Distribution models are used to represent system communication requirements for distributing the data, processes, and interfaces to different geographical locations.

Variations: All types of projects need to go through this activity.

4.4.3.3 Build Discovery Prototype

Purpose: The purpose of this optional activity is to (1) establish user interface requirements, and (2) discover detailed data and processing requirements interactively with users through rapid development of sample inputs and outputs.

Inputs/ Process/ Deliverables: This activity is very relevant to the construction industry as the people in the construction industry are very aware of their requirements but most of them cannot express them without actually seeing them. Requirement prototypes are used to understand the user interface requirements. Requirement prototypes are a simple mock-up of screens and reports that are intended to help system analysts discover their requirements. Discovered requirements are added to the information system logical models. This activity occurs in parallel with the system modeling activity and it occurs, as deemed appropriate or desirable, by the system analysts.

Variation: Prototypes are very helpful to identify user requirements for user interfaces, reports and input forms, especially while developing a customized systems.

4.4.3.3.4 Prioritize CM Requirements

Purpose: The purpose of this activity is to prioritize requirements for a new information system. It is not the intent of this activity to eliminate some requirements. It is only to recognize that some requirements can be implemented later than others.

Inputs/ Process/ Deliverables: The deliverables of these activities are the business requirements' priorities. Prioritizing helps system analysts to make decisions about implementation of business requirements in case the project goes over budget or behind schedule. In such cases, based on the priorities, system analysts can make decisions about implementing some of the requirements of a

later stage. All business requirements can be prioritized in terms of mandatory, desirable or optional categories.

CM Example: Development of a project intranet can be prioritized and may be developed after all essential systems are up and running.

Variations: All types of projects need to go through this activity.

4.4.3.3.5 Modify the Project Plan and Scope

Purpose: The purpose of this activity is to modify the system development project plan to reflect changes in the scope that have become more apparent during the requirement definition.

Inputs/ Process/ Deliverables: After completing all activities in the definition phase, a revised project plan is developed which covers the remainder of the project. The project schedule and budget are reevaluated and new changes are negotiated with the project director. This process is the last activity of the project analysis part of the system development. Therefore, a requirements statement which is a consolidation of all documents generated in the survey, study and definition phases is developed and stored in a project repository as a reference. The requirement statement should not be frozen as the requirements may change during the life cycle of the project and some changes may need to be made. The *requirement statement* should act as a guiding document for the future activities and project plans. At the end of the analysis phase, the system development goes smoothly into the design part of the system development process.

Variations: All types of projects need to go through this activity.

4.4.3.4 Configuration Phase

The primary objective of the configuration phase is to identify and research alternative manual and computer-based solutions to support a target information system, to evaluate the feasibility of alternative solutions, and to recommend the best overall alternative solution. This is the first time that the focus of the information system development shifts from the business requirements to physical implementation. The following sections describe the activities involved in the study phase along with an example from the construction project management field related to each activity. Figure 4.9 shows the deliverables generated from each activity and the relationships between these deliverables.

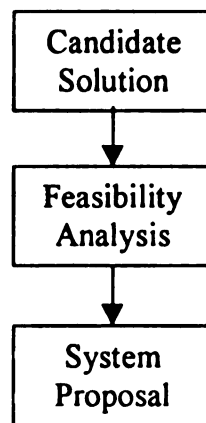


Figure 4.9 Configuration Phase of CMSDM

4.4.3.4.1 Define Candidate Solution

Purpose: The primary purpose of this activity is to identify alternative candidate solutions for the business requirements defined during system analysis.

Inputs/ Process/ Deliverables: Based on the business requirements, candidate solutions are identified. Most of the time these solutions define the application architecture of the system. Normally a particular software solution is not selected. But in the case of an existing corporate application architecture, the selected architecture is tested for business requirements and the design activities are started using the same solution.

CM Example: The system analyst needs to make decisions such as whether the project needs a networked solution or a single user system. A typical solution can be a progress planning and cost control system installed on a client-server platform with multiple and remote access to cost and time data.

Variations: All types of projects need to go through this activity.

4.4.3.4.2 Analyze Feasibility of Alternative Solutions

Purpose: The purpose of this activity is to evaluate the alternative candidate solutions according to their economic, operational, technical, and schedule feasibility.

Inputs/ Process/ Deliverables: The characteristics and features of the solutions identified earlier are compared to each other and evaluated against four sets of criteria. A first criterion, **technical feasibility**, identifies the technical practicability of the solution. It looks into the issues such as whether or not the staff has

technical expertise to build and operate this system. The second criterion, **operational feasibility**, identifies whether or not the solution can satisfy the business requirements. The third criterion, **economical feasibility**, evaluates the solutions for cost-effectiveness. The fourth criterion, **schedule feasibility**, evaluates the time required to finish the system development project.

CM Example: Identification of a time control software that best suits the project requirements based on a feasibility study.

Variations: All types of projects need to go through this activity.

4.4.3.4.3 Recommend a CM System Solution

Purpose: The purpose of this activity is to select a candidate solution having "best overall" operational, technical, economical, and schedule feasibility.

Inputs/ Process/ Deliverables: Based on the analysis done in the study phase, a solution having best "best overall" operational, technical, economical and schedule feasibility is selected. Based on the recommended solution, a written and verbal system proposal containing an analysis of alternative systems is presented to the project director. Then the project director makes the final decision about acceptance of the proposal. Generally, a proposal is selected considering the trade-off between time, cost and features offered by the solution.

Variations: All types of projects need to go through this activity.

4.4.3.5 Procurement Phase

The procurement phase includes identification of software and hardware criteria that can satisfy the recommended solution for the target information system. On the basis of these criteria, vendor proposals are solicited, evaluated, ranked, selected and recommended to the system owner. After awarding the contract to the vendors, system integration criteria are developed. Design of the information system starts after the procurement phase is finished. The following sections describe the activities involved in the procurement phase. Figure 4.10 shows the deliverables generated from each activity and the relationships between these deliverables.

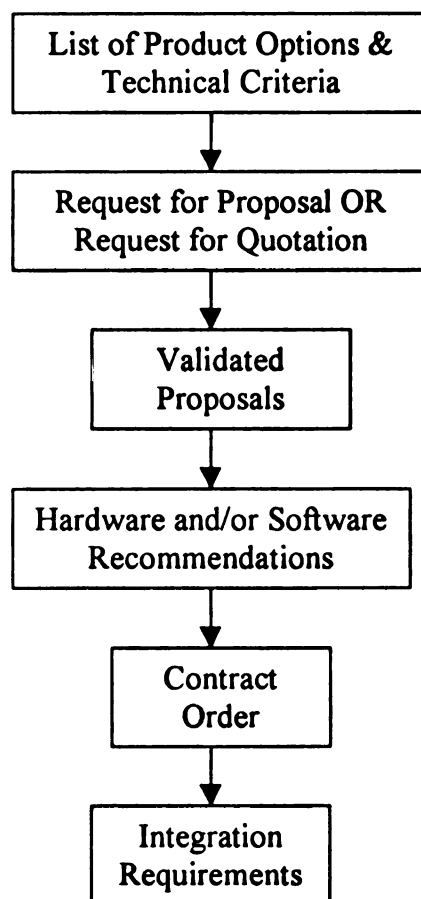


Figure 4.10 Procurement Phase of CMSDM

4.4.3.5.1 Research Technical Criteria and Options

Purpose: The purpose of this activity is to research technical alternatives to specify important criteria and options that will be important for the new software and/or hardware that are to be selected.

Inputs/ Process/ Deliverables: The primary deliverables of this activity include lists of potential vendors, product options and technical criteria. Technical criteria are identified based on the hardware and/or software requirements identified in the configuration phase. Product options and potential vendors are identified using various sources such as trade magazines, trade shows and sales persons. Internal organizational standards can also influence the software and/or hardware options.

CM Example: Considering the tight schedule requirements for delivering system solutions for construction projects, one can hardly go through all of the different product options. Therefore, it is always a better option to select a product based on the research and survey done at the organizational level.

Variations: All types of projects need to go through this activity.

4.4.3.5.2 Solicit Proposals from Vendors

Purpose: The purpose of this activity is to solicit product proposals or quotes from candidate vendors.

Inputs/ Process/ Deliverables: The primary deliverables are requests for proposal (RFP) or requests for quotation (RFQ) that are to be received by the candidate vendors. RFPs are used when the product has not been selected, while RFQs are used when product has been selected. The primary purpose of an RFP

is to communicate requirements and desired features to prospective vendors. Requirements and desired features should be categorized as mandatory (must be provided by the vendor), extremely important (desired from the vendor but can be obtained in-house or from a third party vendor), or desirable (can do without it). The primary purpose of RFQ is get quotations for the selected product.

CM Example: Proposals can be accepted from different scheduling product distributors such as Primavera Project Planner and MS Project.

Variations: All types of projects need to go through this activity.

4.4.3.5.3 Validate vendor Claims and Performance

Purpose: The purpose of this activity is to validate requests for proposals and/or quotations received from vendors.

Inputs/ Process/ Deliverables: Vendor proposals are validated on the basis of a demonstration of software packages and references to the manuals. Based on these validations, vendor proposals are selected for further evaluation.

Variations: All types of projects need to go through this activity.

4.4.3.5.4 Evaluate and Rank Vendor Proposals

Purpose: The purpose of this activity is to evaluate and rank all validated vendor proposals.

Inputs/ Process/ Deliverables:: A cost-benefit analysis is used to evaluate and rank the validated proposals. Based on the rankings, the proposals are recommended to the project director for a final decision.

Variations: All types of projects need to go through this activity.

4.4.3.5.5 Award Contract and Debrief Vendors

Purpose: The purpose of this activity is to negotiate a contract with a vendor who supplied the winning proposal and debrief those vendors with losing proposals.

Inputs/ Process/ Deliverables: After getting a final approval of the selected proposal, the system analyst should negotiate the contract with the vendor. Negotiations should include issues such as final price, site licensing fees, corporate license fee, corporate discounts, maintenance terms and technical support.

Variations: All types of projects need to go through this activity.

4.4.3.5.6 Establish Integration Requirements

Purpose: The purpose of this activity is to establish the requirements necessary for integrating the awarded vendor's products into the existing information system or in to other parts of the information system

Present Finding and recommendations: This step is accomplished by reviewing the data, and process models, and the hardware and software specifications of the awarded vendor's products. Based on this study, sets of integration requirements are developed to ensure that a system works in harmony with other systems.

CM Example: When a spreadsheet based scheduling system is replaced by Primavera Project Planner, one needs to identify the technical requirements of integrating the schedule and cost data.

Variation: When a new system is developed, some integration requirements need to be developed between commercial systems and/or customized systems to ensure that they work together as a single system.

4.4.3.6 Design and Integration Phase

The central idea behind the design and integration phase is to convert the models developed in the definition phase to models in terms of the selected technology so that the system builder can build a new system on the selected platform that can satisfy the business requirements. The following sections describe the activities involved in the design and integration phase. Figure 4.11 shows the deliverables generated from each activity and the relationships between these deliverables.

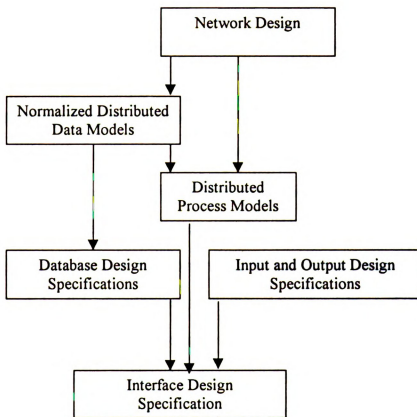


Figure 4.11 Design & Integration Phase of CMSDM

4.4.3.6.1 Design Networks

Purpose: The purpose of this activity is to design network topography and network components.

Inputs/ Process/ Deliverables: A network is designed based on the network decomposition diagram and on the network connectivity diagram developed in the system analysis phase. This activity involves identification of the network topography based on the geographical position of the project office, as well as on selection and configuration of network components such as bridges, hubs, switches, and cables.

Variations: This activity need not be performed in case of a stand alone system.

4.4.3.6.2 Analyze and Distribute Data

Purpose: The purpose of this activity is to develop a good data model.

Inputs/ Process/ Deliverables: An initial data model is developed in the definition phase. But that data model does not consider issues such as the selected database development platform or the constraints related to this platform. System users are involved in the development of the data models and the data characteristics. After developing improved data models, a network topology diagram is developed. After that data stores are distributed to different locations. The process models may also be changed with respect to new data models. The principal deliverables of this activity are normalized distributed data models and revised process models.

CM Example: If a scheduling system is used as a shared application, then the project data is stored on a server while in the case of a single user system, it's saved on the user machine.

Variation: The normalized data models are required only when a customized system is developed using system development tools. In the case of networked solutions for construction projects data are stored on a single server for most of the shared applications. For single user applications, one needs to identify which users are using each application, and then distribute the data accordingly.

4.4.3.6.3 Analyze and Distribute Processes

Purpose: The purpose of this activity is to analyze and distribute system processes to fulfill the network requirements of the new system.

Inputs/ Process/ Deliverables: Processes are distributed throughout the network based on the data model, process model and application architecture.

CM Example: When a scheduling system is designed, one needs to identify the locations where the scheduling data will be stored and the workstations from which that data will be accessed.

Variations: In the case of networked solutions, most processes are performed on client computers. For single user applications, one needs to identify which users are using each application and then distribute the processes accordingly.

4.4.3.6.4 Design Database

Purpose: The purpose of this activity is to prepare technical design specifications for a database that will be able to adapt to future requirements and expansions.

Inputs/ Process/ Deliverables: Database schema are developed based on the data models and the selected development platform. The database schema are structural models for a database. They are models of records and relationships to be implemented by the database. Technical design specifications include data tables, data fields, and relationships between the tables and indexes.

Variations: No database design is required when commercially available solutions are purchased. In the case of commercially available applications, one needs to analyze the database schema of the ready solution to understand possible customizations for certain data elements or reporting requirements. The data structure of commercially available solutions also need to be analyzed to identify any attributes, which may be missing compared to data models developed in the analysis phase. In such a case, those attributes need to be added as a custom data item within the same application or within the customization environment.

4.4.3.6.5 Design Computer Output and Input

Purpose: The purpose of this activity is to prepare technical design specifications for user inputs and outputs.

Inputs/ Process/ Deliverables: This activity is based on the input and output design requirements specified in the system analysis. Design of the computer input consists of three processes. The first is a data capture mechanism, which identifies

the data to be inputted. The second is data conversion, which is the process of translating the source document into a machine-readable format. The third is data input, which is the actual entry of data in a machine-readable format into the computer. A system analyst needs to design source documents, which are paper forms used to record data that will eventually be entered into the computer. A system analyst also needs to design a data capture mechanism and computer input screens based on the user requirements identified in the data flow diagram. The input screens should be designed similarly to the source document to make data entry easier. A system analyst also needs to design output related specifications such as the format and layout of reports. A system analyst needs to work closely with the system users to identify user requirements and preferences. Prototyping is used predominantly in designing the system inputs and outputs.

CM Example: In most construction subsystems, data such as requisitions sent by a contractor, are captured on a piece of paper and then recorded in a computer in a batch or on-line format.

Variations: Input screens need not be designed for ready commercially available solutions. In the case of a ready commercially available solution, custom reports are designed based on user requirements. If none of the commercially available solutions can satisfy the unique reporting requirements, then custom reports need to be developed using report writing tools. This generally requires accessing databases in those applications. The data structure of the commercially available software identified in the database design phase can be helpful in developing customized reports.

4.4.3.6.6 Design On-line User Interface

Purpose: The purpose of this activity is to prepare technical design specifications for the on-line user interfaces.

Inputs/ Process/ Deliverables: The basic component of a user interface consists of a menu which facilitates user movement from one screen to another. A state transition diagram is used to represent the possible movements among the different screens. This component is developed based on the interface design requirements identified in the system analysis phase. A system designer needs to work closely with the users to make easy-to learn and easy-to-use interfaces. Human engineering plays a major role in designing the interfaces.

Variation: This activity is required only for customized system development projects.

4.4.3.6.7 Present and Review Design

Purpose: The purpose of this activity is to present final design specifications and plan future project activities.

Inputs/ Process/ Deliverables: A technical design statement is prepared after completing all design activities. This acts as a guiding source for the activities in the construction phase. A project plan is revised and a detailed project plan is developed for all of the remaining activities of the project.

Variation: This activity can be expedited in case of an urgent system request.

4.4.3.7 Construction Phase

System implementation involves the construction of a new information system and the delivery of that system into production. The purpose of the construction phase is two-fold:

- To build and test a functional system that fulfills the business and design requirements.
- To implement the interfaces between the new system and an existing system.

The following sections describe the activities involved in the construction phase along with an example from the construction project management field related to each activity. Figure 4.12 shows the deliverables generated from each activity and the relationships between these deliverables.

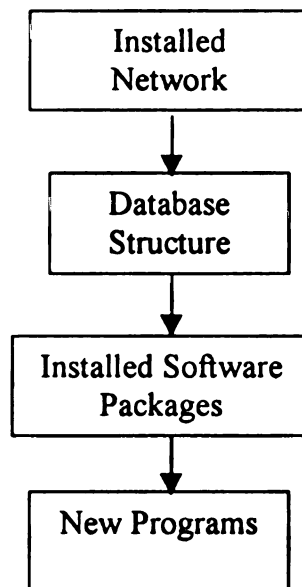


Figure 4.12 Construction Phase of CMSDM

4.4.3.7.1 Build and Test Network

Purpose: The purpose of this activity is to build and test the new network.

Inputs/ Process/ Deliverables: This activity is based on the network design requirements identified in the design phase. The networks are implemented according to these requirements. This activity includes installation of hardware such as the server, workstations, network interface card, and cabling. It also includes software-related activities such as installing the network operating systems on the client and server machines. This network is tested after installation is done for the expected business requirements.

Variations: This activity is applicable only to the networked solutions. In single user systems, peer-to-peer networks are developed to share data and resources. But in that case only cabling needs to be done. In the case of a single user system, only hardware related to workstations is installed and tested.

4.4.3.7.2 Build and Test Databases

Purpose: The purpose of this activity is to build and test databases.

Inputs/ Process/ Deliverables: The database is developed based on the database design requirements specified in the technical design statement. The deliverable of this activity is an unpopulated database structure. A database platform is installed before developing the database structure. This database structure is tested with some test data.

Variations: This activity is applicable only to the custom application development.

4.4.3.7.3 Install and test New Software Packages

Purpose: The purpose of this activity is to install the software packages.

Inputs/ Process/ Deliverables: After receiving the software packages and documentation from the software vendor, they can be installed. The installed software packages are tested for expected system performance.

Variations: This activity is not applicable for customized system solutions. In the case of a ready commercially available solution, this activity also includes the development of source documents and custom reports.

4.4.3.7.4 Write and Test New Programs

Purpose: The purpose of this activity is to develop all of the programs which need to be developed in-house.

Inputs/ Process/ Deliverables: All customized applications are developed using technical design statements. The plans for programming and test data are previously developed in the system design stage.

CM Example: This activity is used to develop customized applications to link different functional subsystems to provide a common working environment. It is also used to develop customized reports using report-writing tools.

Variation: This activity is required only for customized system development projects.

4.4.3.8 Delivery Phase

The purpose of the delivery phase is to facilitate a smooth conversion from the old system to the new system. The following sections describe the activities involved in the delivery phase along with an example from the construction project management field related to each activity. Figure 4.13 shows the deliverables generated from each activity and the relationships between these deliverables.

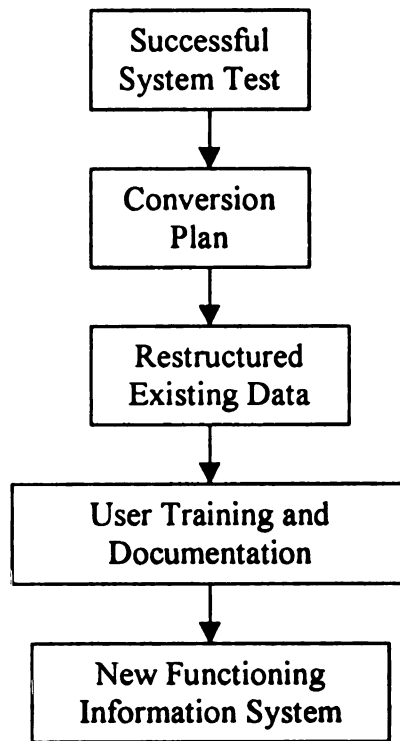


Figure 4.13 Delivery Phase of CMSDM

4.4.3.8.1 Conduct System test

Purpose: The purpose of this activity is to test all of the software packages and custom-built programs to ensure that they work together.

Inputs/ Process/ Deliverables: System tests are conducted using test data. System tests may result in the modification of system programs. After modifications, system tests are conducted again and this iteration continues until a successful system test is developed.

Variation: This activity is required only in the case of systems consisting of multiple subsystems sharing data and information with each other.

4.4.3.8.2 Prepare Conversion Plan

Purpose: The purpose of this activity is to prepare a conversion plan for smooth transition from the old system to the new system.

Inputs/ Process/ Deliverables: A conversion plan including a schedule for populating the databases, end-user training and documentation, and a strategy for converting from the old system to the new system are produced by this activity.

There are four types of conversion strategies. The first is an abrupt cut-over where the whole system is replaced by a new system at the same time. The second is a parallel conversion where both the old and new systems are run at the same time, and after fixing all problems the new system can be introduced gradually or abruptly. The third is a location conversion where systems are replaced gradually at different locations. The last is a staged conversion where each successful version of the system is converted as it is developed.

Variation: In a new project environment, an information system is introduced abruptly after training the users.

4.4.3.8.3 Install Databases

Purpose: The primary purpose of this activity is to populate a new system with existing data from the old system.

Inputs/ Process/ Deliverables: Normally some form of data restructuring is required while transferring the data. Data are transferred manually or by developing some transition programs which can populate data automatically to the new system.

Variations: In the case of a new information system development effort, the system is normally planned to be delivered before the actual start of construction and the generation of substantial data. In the case of system modification, the old data are transferred using general tools such as spreadsheets or database applications.

4.4.3.8.4 Train System Users

Purpose: The primary purpose of this activity is to provide training and documentation to the system users and to prepare them for a smooth transition to the new system.

Inputs/ Process/ Deliverables: Training can be provided in-house or through external sources to all users. System vendors provide training for most of the commercially available packages, while system analysts provide training for all the

customizations. User-friendly, step-by-step system documentation is very essential for successful system implementation. User manuals should be developed and made accessible to all the users.

CM Example: System users such as project managers and project engineers need to be trained on the new system. Training is essential, especially in a construction project environment where user computer literacy is not very high.

Variation: All types of projects need to go through this activity.

4.4.3.8.5 Convert to New System

Purpose: The primary purpose of this activity is to convert to a new system from the old system.

Inputs/ Process/ Deliverables: A conversion plan and all activities mentioned above are followed to complete a system development process. The whole system development process and experience are evaluated with the team members and used for future development efforts. From here onwards, the system support phase starts.

Variation: All types of projects need to go through this activity.

4.4.3.9 System Support

The system support phase includes activities such as monitoring system performance, solving system performance issues, documenting changes and supporting system users on working with the system. One of the main issues

related to the system support in a construction project environment is change management.

Change Management: The construction project team is very dynamic in nature. People are frequently replaced from or added to the project team. New members of the project team need to get accustomed to the project information system. A user-friendly system, user system documentation, and early quality training could help new team members in getting familiar with the project information system quickly. As the project progresses, new user requirements are identified. These new system requirements need to be justified on the basis of tradeoffs between the new system features and resources spent on system modification. If these requirements are found justifiable, then a fresh system request should be filed and the system should go through the process of system modification using phases and activities of CMSDM.

4.5 Major Variations in CMSDM

CMSDM describes the core framework of information system development in a construction project environment. Figure 4.14 which is formed by the combination of figures related to individual phases, shows the deliverables produced in the different phases of CMSDM and the interdependence among these deliverables. CMSDM is a generic methodology for projects in the construction industry, which needs to be applied to a particular project and is based on the project and system variables. Combinations of these variables form a unique project environment, which needs a different approach for developing an information system. In those

variations some of the activities may be merged or exploded in order to get details according to the project requirements. For example, if a commercially available software solution is identified, then activities such as design of input screens, design of databases, development of normalized data models and writing programs can be replaced by detailed activities such as design of source documents, design of reports, and software customization. Some of the most important variables which affect these deviations of methodology are identified rather than describing the different deviations of the methodology itself. All of the variables are divided into two categories.

- Project specific variables
- System specific variables

The project variables influence all stages of a project life cycle while the system variables have an effect after the system architecture is decided in the system configuration phase. Based on the decisions taken in the configuration phase, the scope and content of the activities in the remaining phases change considerably.

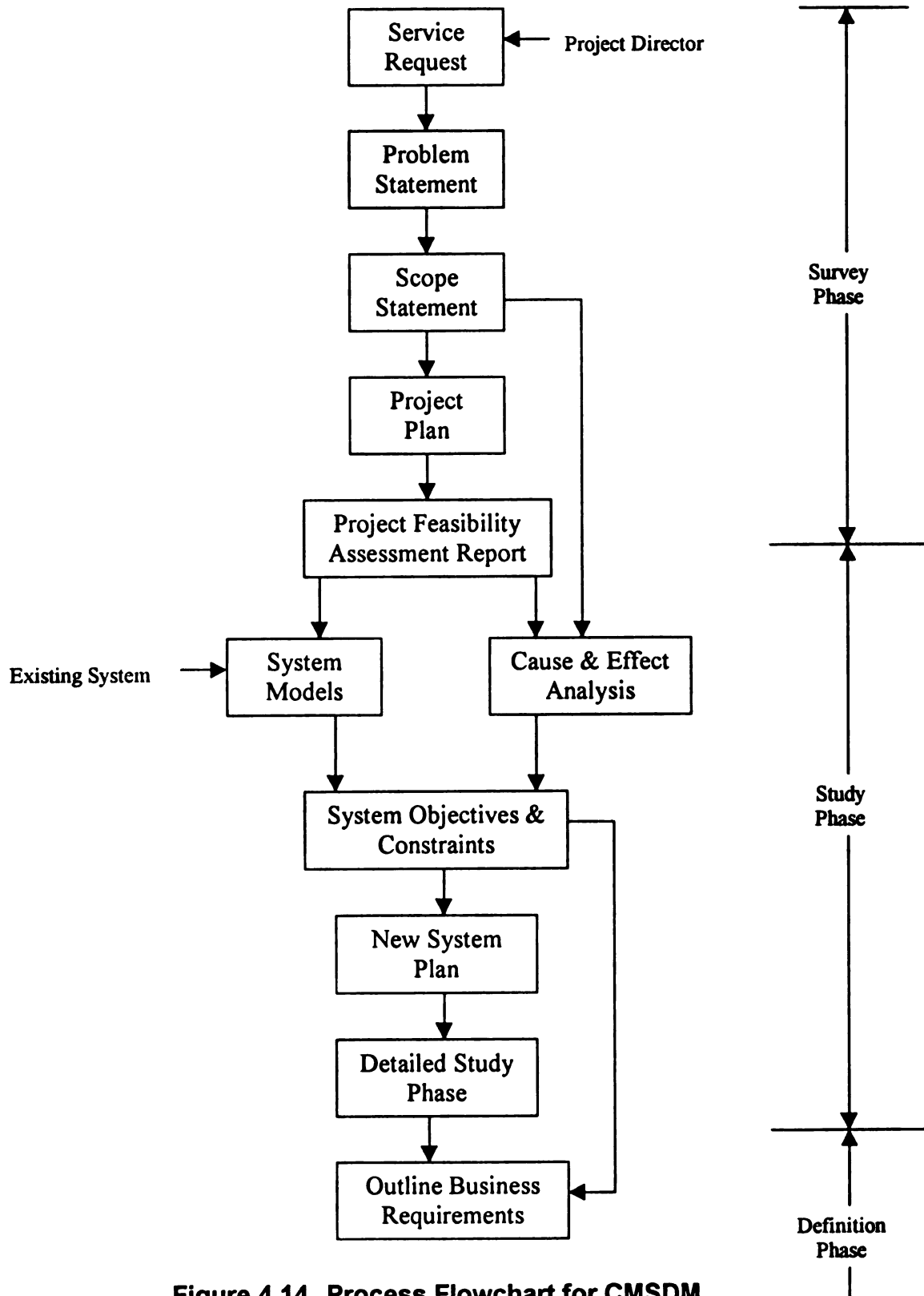


Figure 4.14 Process Flowchart for CMSDM

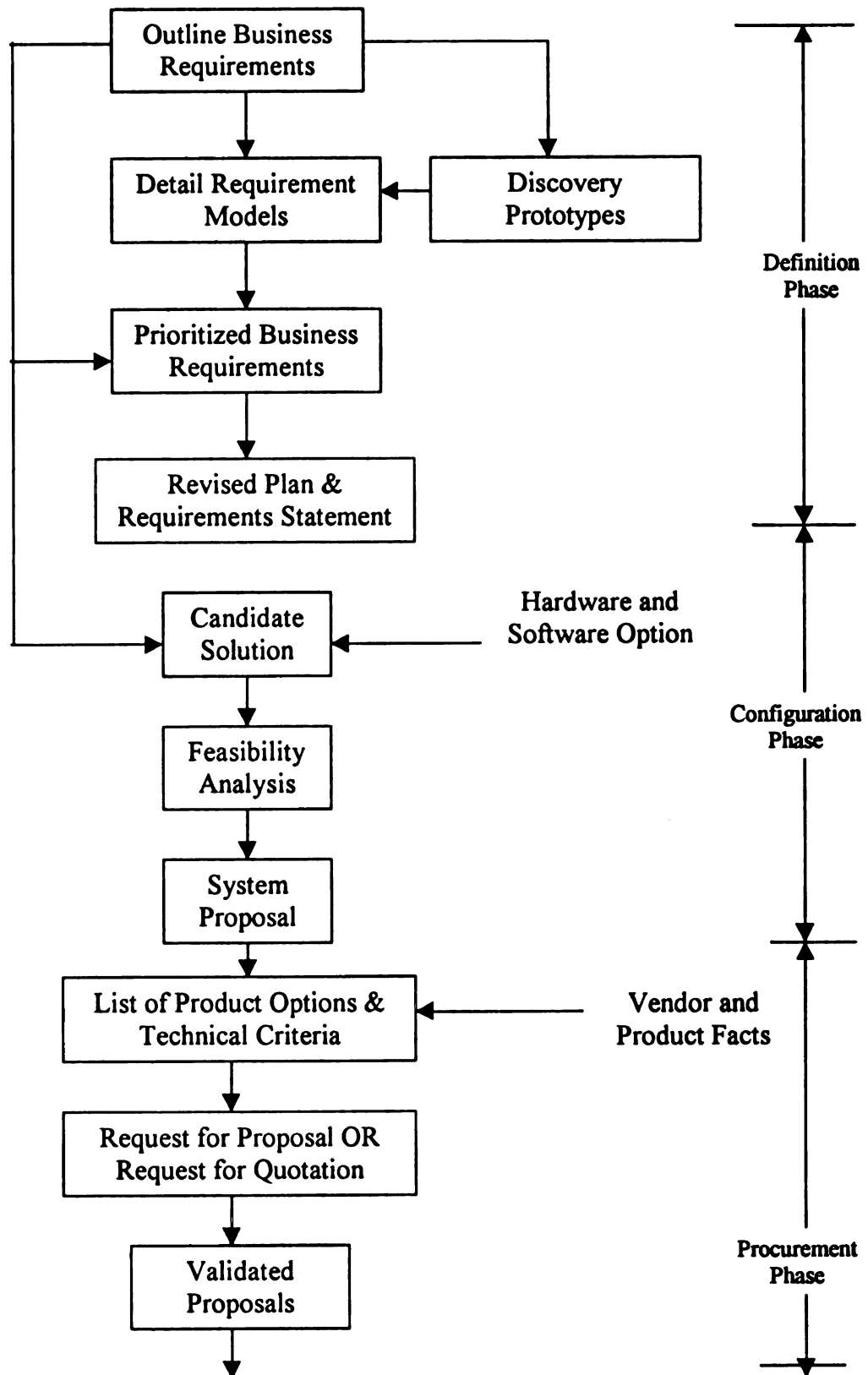


Figure 4.14 Process Flowchart for CMSDM (Cont.)

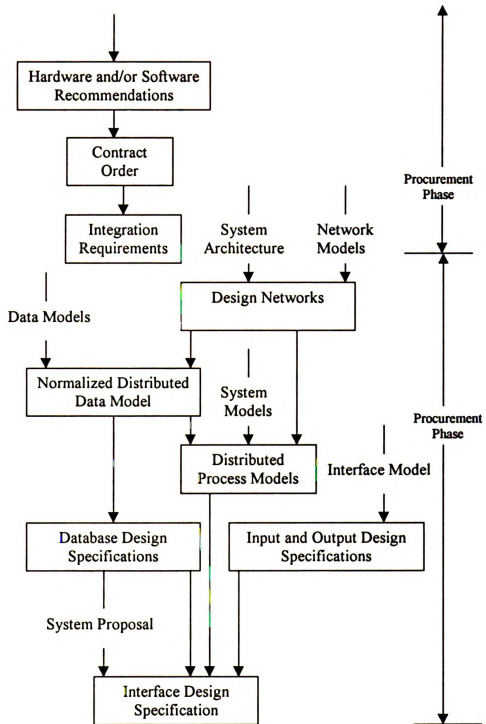


Figure 4.14 Process Flowchart for CMSDM (Cont.)

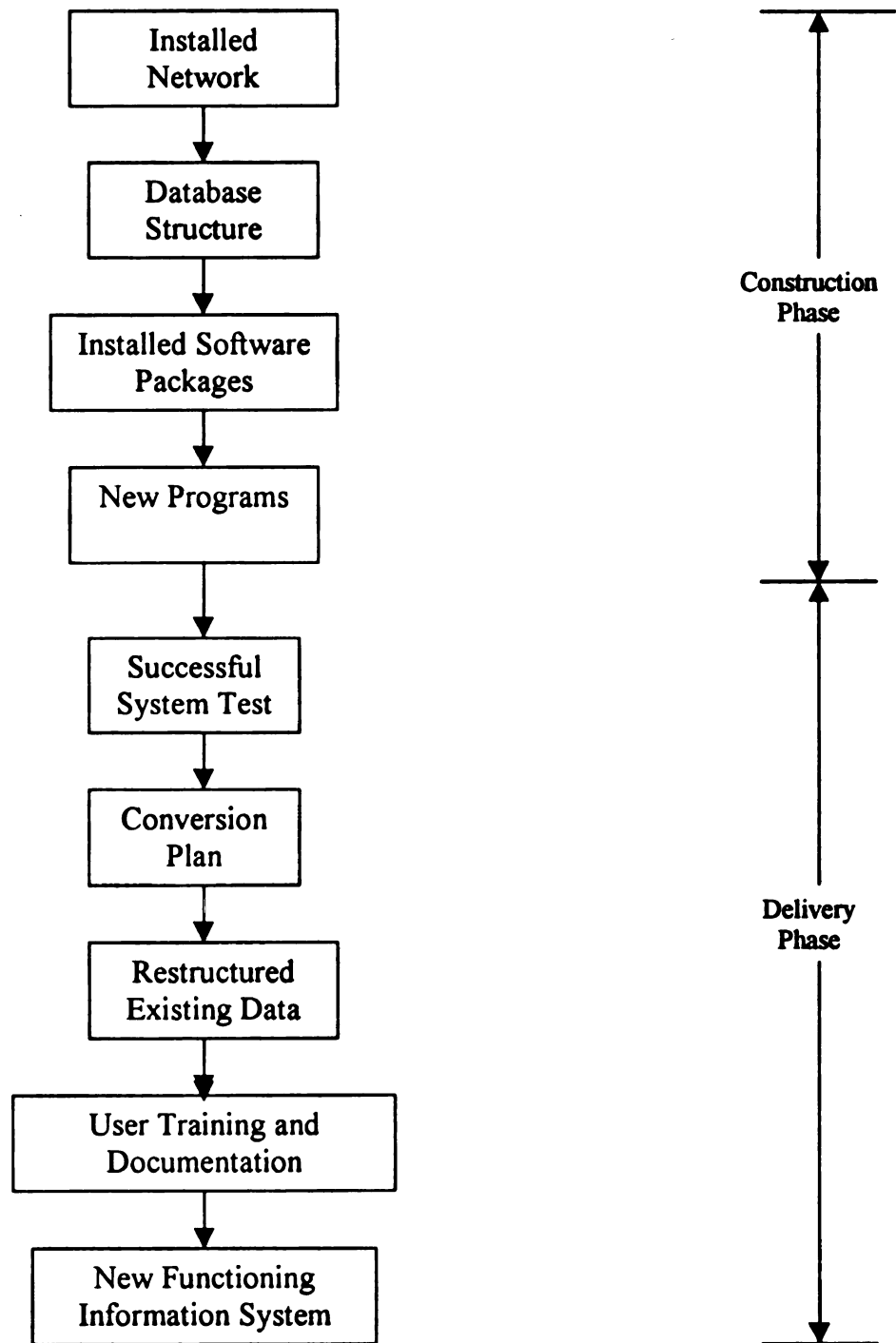


Figure 4.14 Process Flowchart for CMSDM (Cont.)

4.5.1 Project specific variables

These variables are based on the characteristics of the construction project. These variables are identified before the start of the system development process and corresponding changes are done in the system development methodology.

- **Project Origination:** An information system development project can be originated as a new system development for a new construction project or as a modification to an existing system. In the case of the modified system, the original system needs to be studied and documented in order to understand the system itself and the integration requirements with respect to the new system. But in the case of the new project environment, only generic construction practices need to be studied.
- **Project control:** There are many activities such as plan and present the project, and present the findings, which are important from a project management point of view. These activities can be altered in case of an urgent system development requirement. But again, an experienced project developer should manage the alteration of these activities as this may lead to a lack of project planning and control.

4.5.2 System specific variables

These variables are identified during a system development effort depending on the decisions taken during the system configuration phase.

- **User Access:** Single user or multi-user system. In the case of multi-user access, a networked system needs to be developed. Such a system needs to go through all of the network development activities.
- **Applications:** Commercially available ready application, customized application, or Hybrid system. Commercially available ready solutions do not need activities such as development of a normalized data model, database design or designing on-line user interfaces. In the case of a custom application, all activities need to be followed, while in the case of hybrid solutions commercially available solutions are customized to the user requirements and, therefore, only some of the activities are followed.
- **Reports:** Reports generated within a commercially available solution or a using reports writing tool. If reports are generated using commercially available reporting tools then the data structure of the commercially available application package needs to be analyzed to customize it and generate reports.

4.5 Summary

This chapter describes the phases and activities involved in the system development methodology for developing a construction management information system in a project environment. Different contents of the methodology such as process, technique or strategy and CASE tool are described. Issues related to the selection of an appropriate system development process and selection criteria are also discussed in detail.

The CMSDM can be applied to different project environments with appropriate modifications according to the project and system variables. It is not the intent of this thesis to describe all variations of the information system development methodologies. The intent is to describe the core framework of system development and the variables which govern different variations. The next chapter demonstrates the application of CMSDM for development of a cost control system for a management team headed by a construction management firm using one variation of CMSDM.

CHAPTER 5

DEVELOPMENT OF COST CONTROL SYSTEM

5.1 Introduction

Chapter 4 describes the phases and activities involved in the development of information systems in a construction project environment. Even after following the steps described in the core methodology, one needs to apply and make appropriate changes according to the project and system variables. This chapter demonstrates the application of CMSDM for development of a cost control system. This cost control system is intended for a construction management firm coordinating a management team for a large commercial construction project.

The following sections describe the construction management contract delivery systems, CM (Construction Management) firms, and the services provided by them before demonstrating the application of CMSDM.

5.2 CM Contract Administration System

Clients of this information system are Construction Management (CM) organizations. Therefore, before developing a system for them, one needs to understand the functioning of construction management organizations to understand the details of construction management cost control requirements from the cost control system.

CM is a process by which a potential project owner engages an agent, referred to as CM, to coordinate and communicate the entire construction

process, including project feasibility, design, planning, letting, construction, and project implementation, with the objective of minimizing the project cost and time, and maintaining the project quality [Adrian 1981].

The definition of four important terms needs to be studied in detail to understand the exact difference between general contracting, turnkey construction and design-build contract delivery system.

Agency: Figure 5.1 shows the difference in the contractual arrangement between general contracting and CM. Unlike the general contractor, an agent (the CM) has an obligation to serve the owner as if the CM were the employee of the owner. An agent has legal authority to represent the owner and to carry out construction management cost control dealings on the owner's behalf. Legally, an agent has the following contractual obligations to its employers: loyalty, obedience, performance, reasonable care, accounting, and information. Therefore, an information system developed for a CM firm should be focused on the owner's information requirements. Levels of data extraction should be high enough to manage the owner's information requirements.

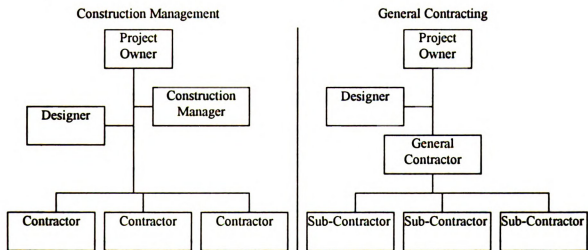


Figure 5.1 Construction management versus general contracting

Coordination and Communication: A CM firm acts as a leader of the owner's construction management team consisting of the owner's representatives, designers, engineers, inspectors, government agencies, material and equipment vendors, and lending agencies. The CM firm has the responsibility to coordinate all parties and communicate project relevant information to the concerned parties. Therefore, an information system developed for a CM firm should focus on data accessibility, data communication and data transparency among all the concerned parties to improve coordination through better communication.

Involvement in the Entire Project Process: The CM firm is involved in the entire project process, including project feasibility, design, planning, bidding, construction and implementation. The CM process is consistent with the systems approach to management. The systems approach indicates that in order to optimize the solution to a problem, one must first interrelate all the component parts. It may follow that some or all of the component parts may have to be performed sub-optimally to achieve optimal performance of the entire system. An information system developed for a CM firm should have different functional capabilities required in different stages of a project and all sub-systems should share data to achieve data and process integration. Therefore, one needs to look into the interfaces between the functional subsystems while designing an information system.

Minimize Project Time and Cost and Maximize Quality: The three variables: time, cost and quality are essential for successful completion of the project. A CM firm has to manage all phases of construction with an objective to minimize cost

and time, and to maximize quality. The time and cost planning and control applications become core applications for the whole management information system for CM firms.

5.2.1 CM Services

As discussed earlier CM firms are involved in all phases of construction projects. Again, services provided in different phases vary according to the project characteristics and owner requirements. An information system requirement of a CM firm depends on the services provided by the firm. Table 5.1 shows the list of services typically provided by CM firms.

5.2.2 Cost Management Activities

Considering the importance of managing costs for success of construction projects, CM firms are involved in many different cost management activities. Cost related activities start from the project conceptualization to maintenance of facilities after construction is completed. Figure 5.2 shows the activities in which CM firms are involved and the dependency between these activities. The bold box in figure 5.2 represents the activity of developing cost control systems whereas the last four activities represent the core processes involved in the cost control operation. The following list includes a brief description of different activities performed by CM firms.

Table 5.1 Services Provided by CM Firms [Adrian 1984]

Preconstruction Phase

- Owner-needs identification study
- Project feasibility study
- Tax analysis of project
- Marketing research for proposed Project
- Assistance in obtaining finance
- Assistance in obtaining permits and zoning
- Budgeting
- Value Engineering
- Parameter Estimating
- Scheduling of Design and preconstruction
- Identification of long-lead items
- Bid Packaging and Phasing
- Awarding contract & Process Paper Work
- Setting out operating procedures and responsibilities

Construction Services

- Detailed Planning and Scheduling
- Construction Phase Estimation
- Operating Procedures
- Supervision
- Inspection
- Handling Paperwork
- Cost and time control system
- Process contractor payment
- Testing the completed project
- Marketing the project
- Property management
- Testing Material

Unit Estimates: The project budget is developed based on the unit cost, historic cost data and component cost. This is a small two-page project budget, which is considered a baseline budget [CRSS Constructors, 1992].

Schematic Design Estimate and Design development estimate: As design progresses, estimates are developed and corresponding suggestions are made to the designers. Value engineering is also performed which leads to some changes related to better use of material and construction processes.

Construction Document Estimates: Estimates are prepared once the detailed plans and specifications are developed. This estimate is used to negotiate bids with the lowest bidder.

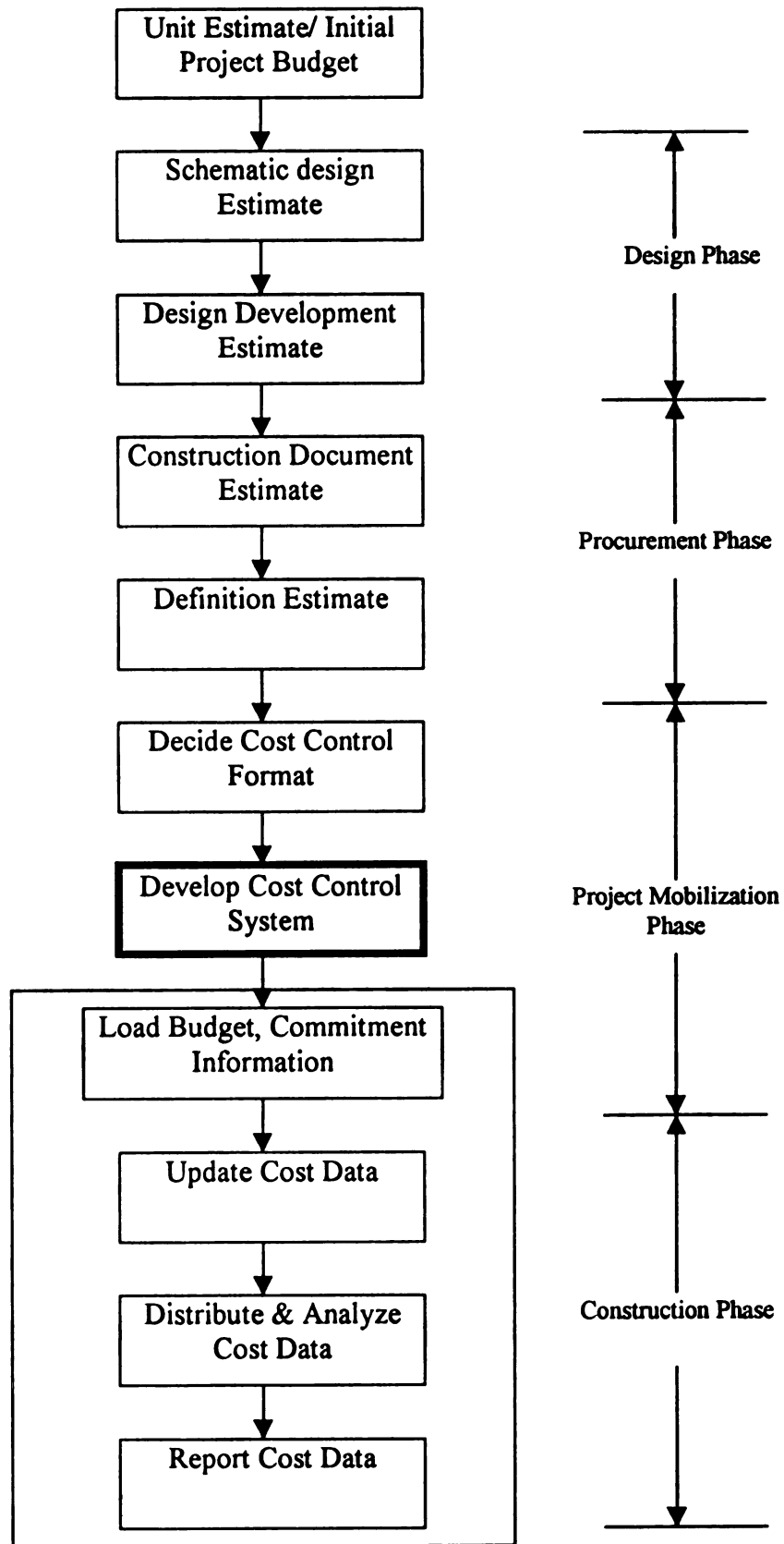


Figure 5.2 Cost Management Activities Performed by CM Firms

Definition estimate: After awarding all contracts, the committed cost is calculated and that becomes a definition or control estimate.

Develop cost control format: Depending on the scope of cost control activities and owner expectations, cost control formats are developed. Cost control formats include entities such as data to be captured (contracts, purchase orders, change orders, cost codes), process of data flows (process of data transmission), reports generated (variance analysis, cash flows). All of these formats need to be communicated to all concerned organizations to achieve communication.

Develop Cost Control System: After identifying the data, processes, interfaces and geographical requirements of a cost control system, the cost control system is developed using appropriate system development methodology.

Load Data: After successful development of a cost control system, cost data such as budget and commitments are loaded into the system. These data become the baseline for monitoring cost performance.

Updating Cost data: With the progress of a construction project, new data are updated in the cost control system and the project status is updated.

Distribute and analyze cost data: Cost data are distributed to cost accounts and analyzed to monitor and control project costs.

Report cost data: Periodic reports are generated to aid decision making and reports are submitted to the project owner to keep the owner informed about the project performance.

5.3 CM Project Environment

This section is intended to describe the domain project environment, which will guide the entire process of system development. This is a hypothetical project domain, which is very close to an actual large commercial construction project managed by a CM contract delivery systems. This project uses the best practices in the industry. [Adrian 1984, Barrie et al. 1982]

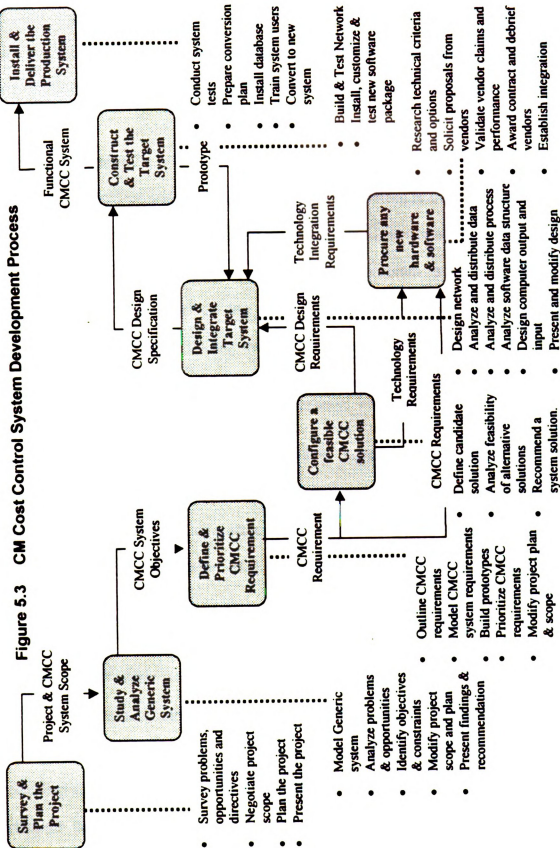
It should be noted that the intent of this chapter is to demonstrate the application of CMSDM defined in Chapter 4 and not to comment about the fictitiousness of the domain project environment. The project environment described below is a large size commercial construction project managed by a CM contract delivery system. This project environment is used to develop a problem statement as a starting point of a system development process. The focus is on the process of system development and not on facts about the project environment.

- The domain project is a typical commercial construction project with an estimated cost of \$250 million managed by a CM contract delivery system
- A cost control system needs to be developed as a part of the project initiation efforts.
- The system should be developed in six weeks of limited project mobilization time available due to the "fast track" nature of project. The allotted budget for system development is \$25,000.

- The owner has given directions to use Primavera Project Planner (P3) [Primavera 1997] as a scheduling system. Therefore the developed cost control system should be able to share data with P3.
- System users include the project director, a number of project managers, a project controls manager, a contract engineer, a scheduler and an estimator. The project director acts as a system owner and the project controls manager acts as a user manager who coordinates the interaction between the system analyst and the system users. The contract expediter is a system user who maintains the system, takes reports and updates data. Project managers update data and use reports for their decision making.
- The time and quality of the system has higher priority compared to the cost aspect.
- A service request is placed with the regional project support group for developing a cost control system and a system analyst is assigned to the development work.

5.4 Development of CMCC System using CMSDM

This section demonstrates the process of construction management cost control (CMCC) system development using the CMSDM within the described project domain. All phases and activities included in this section are derived from the CMSDM described in Chapter 4. Figure 5.3 describes the phases and activities used in development of construction management cost control (CMCC) systems.



The boxes in figure 5.3 represent the phases involved in development of the CMCC system and arrows represent the data flow between them. The dotted lines connect the phases and the activities involved in individual phases.

5.4.1 Survey Phase

Survey Problem Opportunity and Directive: This system is triggered by a high priority system request. After a number of interview sessions with the project director, the system analyst has developed a problem statement. These requirements are prioritized on the basis of urgency of these requirements, visibility to the construction project owner and annual benefits. Table 5.2 shows the sample problem statement and requirements are listed in order of priority.

Negotiate the Project Scope: After discussing the problem statement with the project director and analyzing the priorities and possible solutions, the system analyst has developed a scope statement. Table 5.3 shows the scope of the system in terms of four system building blocks: data, process, interface and geography.

Plan the Project: After defining the scope of the project, system analysts need to prepare a schedule and budget for the project and get it approved from the project director. The budget is developed based on past experience in developing similar projects and studying current industry trends. The schedule is developed based on the available mobilization time. Figure 5.4 shows the

baseline plan for the future phases. The system analyst also needs to identify the appropriate deviations of the system development methodology, which can be used for this project.

Table 5.2 Cost Control System: Problem Statement

No.	Requirements	Urgency	Visibility	Priority	Proposed Solution
1	Manage cost related documents such as contracts, purchase orders, change documents	High	High	High	Cost control application
2	Multiple access to cost data/ security (client access)	High	Medium	High	Client/ server application
3	Periodic reporting	High	High	High	Reporting tool
4	Custom reporting	High	Medium	Medium	Custom reporting package
5	Online updating	High	Medium	High	Networked access
6	Remote access for contractors	Low	Low	Low	Remote dial-in access
7	Automated interface with scheduling system	Medium	Low	Medium	Interface with scheduling system

Present the Project: Even though in the construction environment, the project director is not interested in the details of system development, it is a good practice to communicate the system scope and goal in a written format to the project team and get written approval from the project director for the corresponding project plan to avoid future conflict. A feasibility assessment report should be developed to communicate developments with the regional project

support group and other system developers to present and discuss possible system solutions.

Table 5.3 Cost Control System: Scope Statement

System Focus	Scope
Construction management data	Contracts, Purchase Orders, Change Proposals, Change Orders, Invoices, Requisition, Trends, Material Delivery
Construction management processes	Loading, Updating all construction management cost control subjects, analyzing the performance by distributing cost to cost accounts, periodic reporting and custom reporting with ability to produce online reports.
Interface	User friendly interface, Automated interface with scheduling system
Geography	Multiple workstations at office location, Remote access for contractors






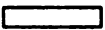


Description	Duration (days)	Barchart
Survey	3	
Study	3	
Definition	5	
Configuration	4	
Procurement	4	
Design	5	
Construction	8	
Delivery	6	

Figure 5.4 Baseline Schedule for System Development Project

5.4.2 Study Phase

The scope of the study phase depends on the unique requirements of the construction project and the developer's past experience with developing such systems. If the system developer is new to the domain industry, it is very important for the system developer to understand the data flow and decision making process involved in a cost control system considering the decision support characteristic of this system.

Model generic system: This activity is used to describe the data and processes used while managing construction projects. Most of the time, a CM firm identifies the project processes in consultation with the owner and communicates them with all other organizations involved in a project. Therefore, the system analyst needs to identify and understand the accepted processes. The system analyst would most probably have discussions with the project control manager to understand the processes. Organizational manuals may be used to identify the processes and develop the vocabulary. Most probably, a CM firm identifies the project processes in consultation with the owner and communicates them with all other entities involved in project. One-page data, process and interface models are developed to understand and validate the intended system behavior. Other modeling techniques such as flowcharts can also be used to represent the decision-making process. These models are further developed to represent user requirements. More information about the construction management cost control objects gathered by a system analyst are given below.

Construction management cost control objects

- **Contract/ Purchase Orders:** Lump sum or unit price contracts and purchase orders form a binding agreement between the owner and contractors. Contracts and purchase orders define the original budget and commitments for the construction project.
- **Proposal/ Change Order:** In the case of a change in conditions, the owner asks the contractors to submit a proposal for additional work or for a reduction in work scope. This proposal, after negotiations, becomes a change order, which is contractually binding on both parties. Proposals and unapproved change orders define the pending changes in budget and commitments. Approved change orders define the approved revisions to the budget and commitments.
- **Invoice/ Requisition:** Contractors and suppliers submit invoices or requisitions for the amount of work performed in a particular period. After identifying the actual work done, the owner approves the requisition amount. Invoices and requisitions define the actual amount paid to the contractors.
- **Trends:** The owner makes changes in the budget or commitment on the basis of possible changes in a project environment. These trends define the estimated revisions to budget and commitment.
- **Cost Codes:** Cost codes define the level of abstraction at which the CM firm wants to monitor cost performance of the project. All cost objects such as contracts, purchase orders, requisitions, invoices, change orders, and proposals are distributed to the appropriate cost code based on the scope of

that cost object. After distribution, the owner analyzes performance at these cost codes. For example, the contract for sitework related activities can be divided into three different cost accounts such as demolition, project sitework, and building sitework. This distribution helps to monitor cost performance at a detailed level.

Construction management cost control Functions

- **Load database:** Before the start of construction, the CM firm needs to load cost objects such as contracts, purchase orders, and cost codes, and distribute these costs to the appropriate cost codes. This database becomes a baseline against which the cost performance can be monitored.
- **Update & distribute database:** As the construction starts, new cost objects such as proposals, change orders, requisitions, and invoices are developed. These cost objects need to be updated during construction and distributed to the appropriate cost code.
- **Prepare reports:** After updating cost objects as soon as possible after their origination, periodic decision supporting reports need to be generated for internal as well as external users at different levels of management.

Decision Making Process

The following flow chart (Figure 5.5) presents the general process of the cost control system in a generic manner. Changes will need to be made according to specific project requirements.

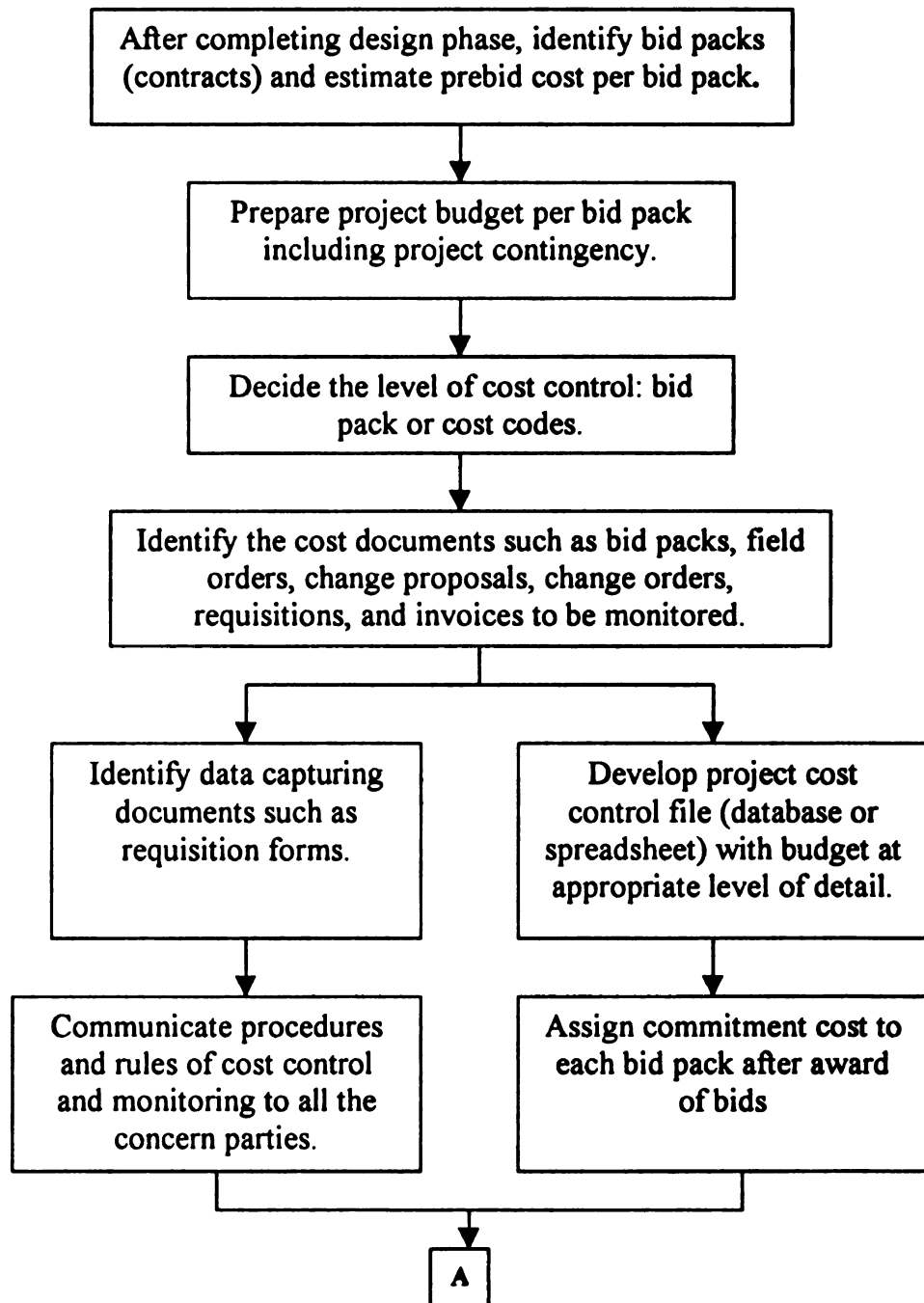


Figure 5.5 Decision Making Process while Managing Cost Control System

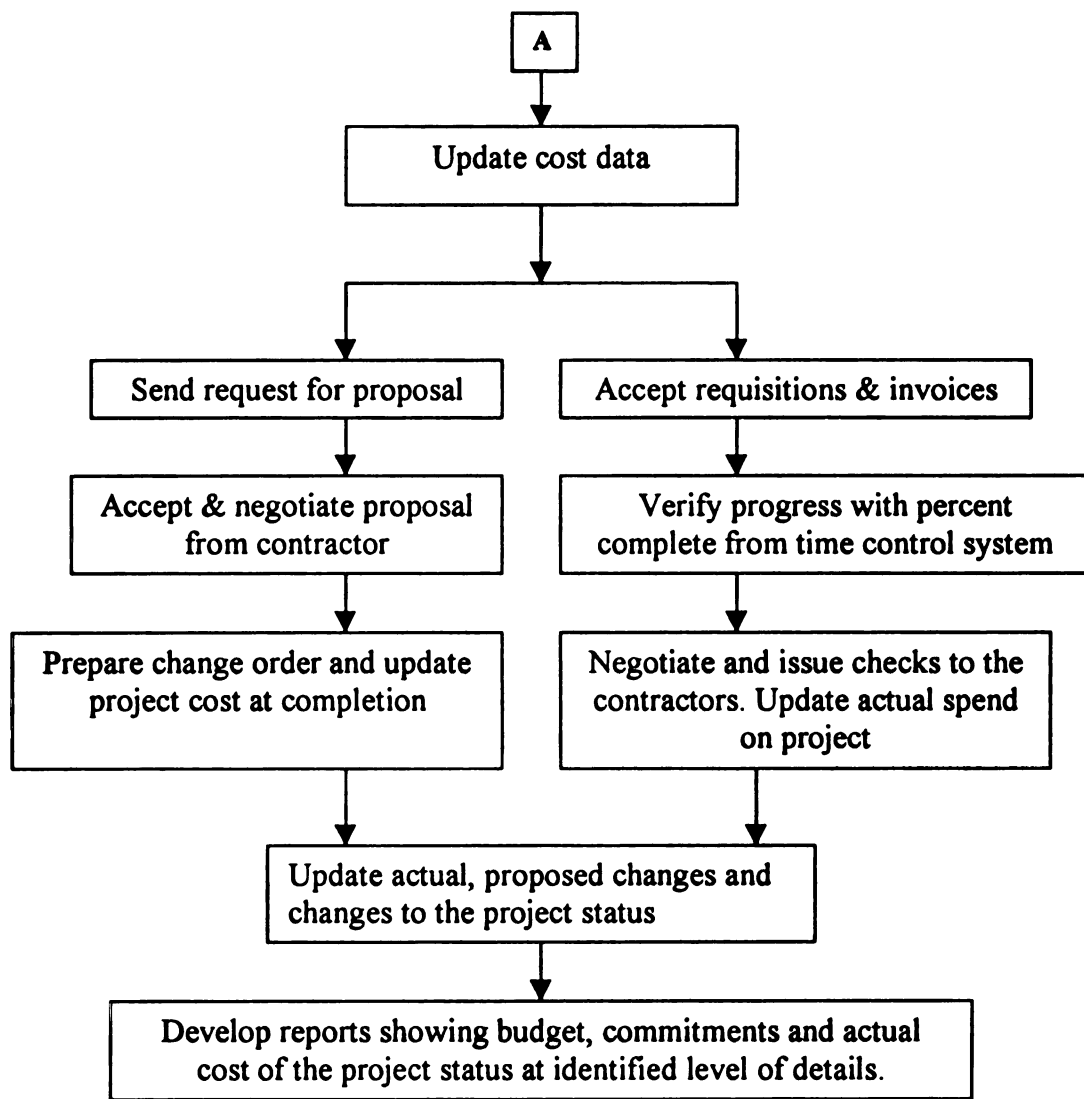


Figure 5.5 Decision Making Process while Managing Cost Control System

(Continued)

Interfaces

Scheduling System: The cost control system has an interface with system users such as the contract expeditors, the project managers, the project directors, and the contractors. It also has an interface with the scheduling system with which it exchanges data such as dates and completed percentages of activities.

Analyze Opportunities: Again considering the fact that this development is intended for new system development, only technology-enabled opportunities are identified. Some of these opportunities are described below.

- **Online data entry through client/server application architecture**

This can help to keep data current and also allows for data to be updated in the system soon after its origination. Project managers can access data from their own workstations rather than requesting data from the system operator. All project users need to be trained in how to update data. Also, a system manager must be available and is responsible for managing system functioning, access, and security on the multi-user client server system.

- **Remote log-in for contractors to send and receive data electronically**

This can help to capture data faster from contractors. Contractors will need to install the selected system on their information system. Contractors may need to be convinced about the advantages and should be treated as part of the team. Also, security issues need to be studied. Again, there are always going to be some organizations that cannot participate in such technology sharing. In that case, an alternative batch processing system has to be continued.

- **Online reporting on a project intranet or some other medium to improve owner visibility.**

Such a system can improve the owner's visibility and get the owner involved in the management operation. It would also help other team members to access data instantly from their work location for decision making. This will not only reduce paperwork considerably but also leads to development and management of a new component of the system.

Establish System Development Objective & Constraints: Based on the discussed opportunities, the following system objectives are identified. These system objectives will be used to evaluate the system performance.

- **The system should be able to load, update and manage all construction management cost control data**
- **All relevant costs should be in the system within 24 hours of receipt.**
- **Reports should be updated according to the CM requirements. The system should be able to develop custom reports anytime. Some other shared media such as a project intranet should be explored to share project information with management teams.**
- **Data entry should be automated as much as possible.**
- **The system should be able to update schedule data automatically after entry.**

The following constraints were observed:

- **Schedule:** System development should be completed in six weeks.
- **Budget:** Cost should not exceed \$25,000.
- **Technology:** All workstations should be IBM compatible.
- **Policy:** Use P3 for the scheduling system.

Modify Project Scope and Plan: The project scope and plan need not be changed considering the fact that all findings in this phase have not changed the scope considerably. The only thing added to the scope is the possible development of a shared medium such as a project intranet to share project reports with the owner and other project teams members.

Present Findings and recommendations: A Joint Application Development (JAD) session may be organized to ensure that all issues have been identified and resolved. JAD sessions should be attended by the entire construction project team. Team members will subsequently be informed about the identified facts, possible change in the scope and a new project plan for the remaining system project.

5.4.3 Definition Phase

After finishing the study phase, a definition phase is used mainly to define, document, and validate user requirements.

Outline Construction Management Cost Control (CMCC) Requirements: The first activity in the definition phase is to make a list containing the construction management cost control requirements. This list is developed from the system objectives and it is used to develop process models.

1. All cost documents should be captured in the system as soon as possible.

1.1 Online data entry from the project office.

1.2 Remote data entry by contractors.

2. Distribute cost data in the required format for analysis.

2.1 Identify cost codes

2.2 Distribute data to appropriate cost codes.

3. Prepare custom, online and possibly paper-less reports.

3.1 Customize reports

3.2 Periodic updating

3.3 Information shared on the sharing device

4. Periodic automatic updating of schedule data

Model CMCC system requirements: The system analyst needs to use fact finding techniques such as interviewing to identify and model user requirements for the cost control system. These models are drawn in a strictly logical manner in order to look for more technical solutions in later phases. These models represent the required system data, process, interface and geographical requirements of the system users. These models are developed based on the models developed in the study phase.

Process Models: Process models represent the workflow through the cost control system. Process models are often represented using data flow diagrams. This model includes the processes, data flows, data stores and external entities, which generate or receive data. Appendix A shows the modeling legends used for data flow diagrams and their application. Figure 5.6 represents the context level data flow diagram (DFD). This diagram defines the cost control system domain, system boundaries, and its interaction with other entities. Table 5.4 describes the processes, external agents, and data flow represented by the context level DFD (Figure 5.6). Figure 5.7 defines the process decomposition diagram for the system. This diagram is represents the decomposition of the cost control process shown in context level diagram (Figure 5.6). Cost control system is decomposed primarily into three processes:

1. Load initial data
2. Update and distribute data
3. Prepare reports

Figure 5.8 is a first level DFD which represents these three processes. Each of these three processes are further decomposed as shown in decomposition diagram to get more processes. Figure 5.8.1, figure 5.8.2, and 5.8.3 represent the detailed DFD for those three processes respectively. The second process, update and distribute data, are further decomposed into three processes. Their DFDs are represented by Figure 5.8.2.1, Figure 5.8.2.2, and Figure 5.8.2.3.

Data Model: Data models represent the data stores identified in the process models and the relationships between these data stores. Data models are

represented by the entity relationship diagram (E-R Diagram). Appendix B shows the legends used in drawing E-R diagrams. Figure 5.9 represents the data model of a cost control system. It should be observed that entities such as "schedule" and "estimates" are external entities and could be linked through interfaces. Entities such as "cost worksheet" and "trends" do not have relational link with other entities. Table 5.5 describes all entities represented in the E-R diagram. This table also illustrates all main attributes of these entities with examples.

Interface Model: Interface models depict the net input to the system, their sources, net output from the system, their destinations, and shared databases. Fig. 5.5 which shows a context level diagram also represents the interface of the cost control system with external people and systems.

Distribution Model: Distribution models help to represent the communication system for distributing the data, processes, and interfaces to the various geographical locations. Fig. 5.10 represents the distribution model of the cost control system.

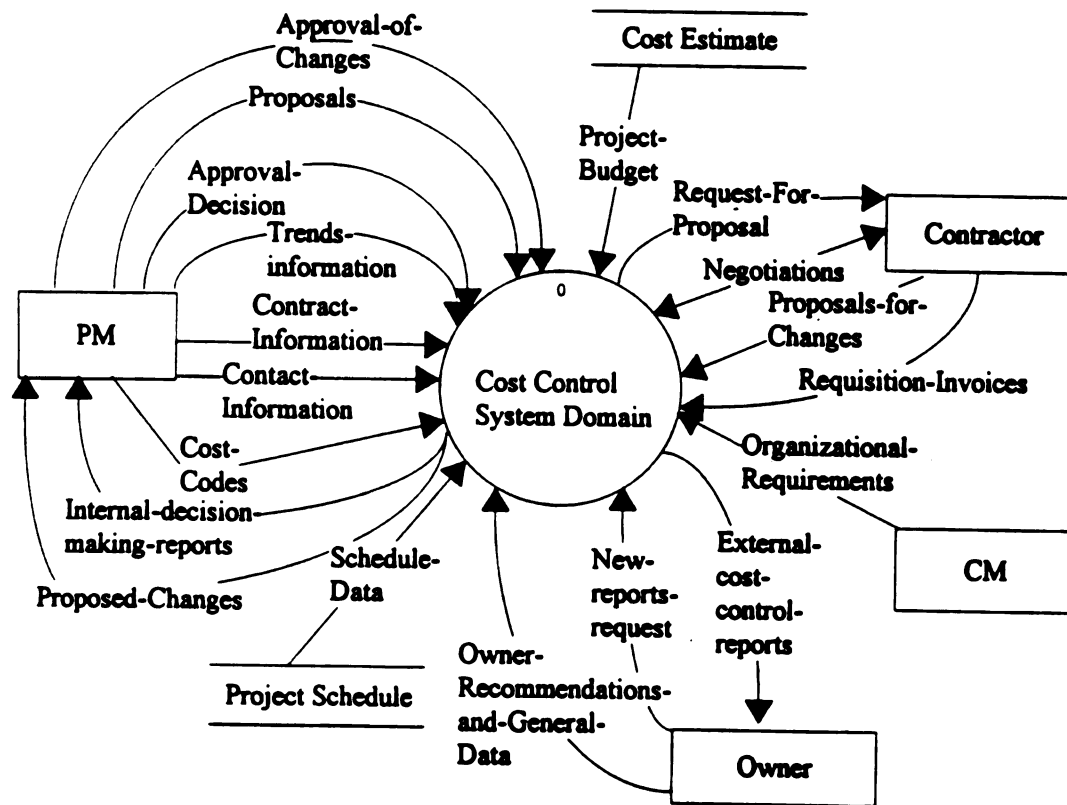


Figure 5.6 Context Level Data Flow Diagram for Cost Control System

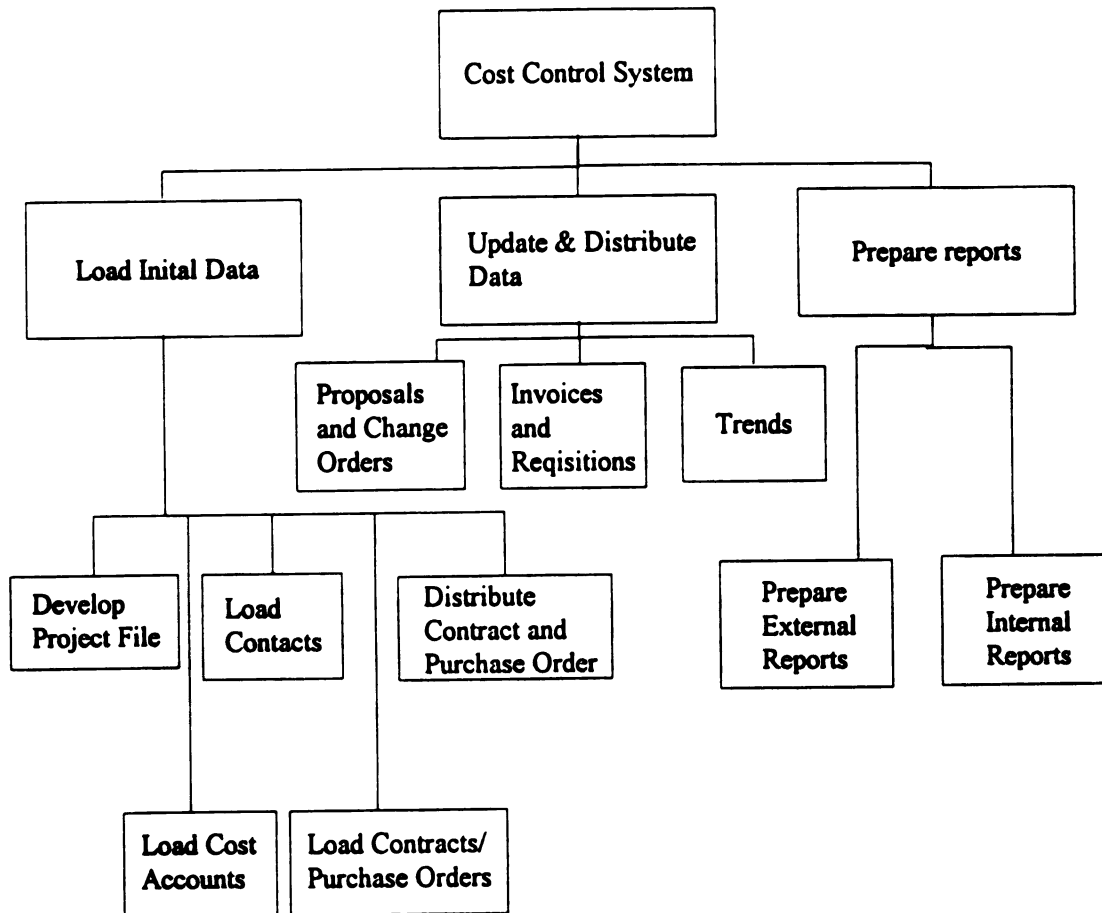


Figure. 5.7 Process Decomposition Diagram for Cost Control System

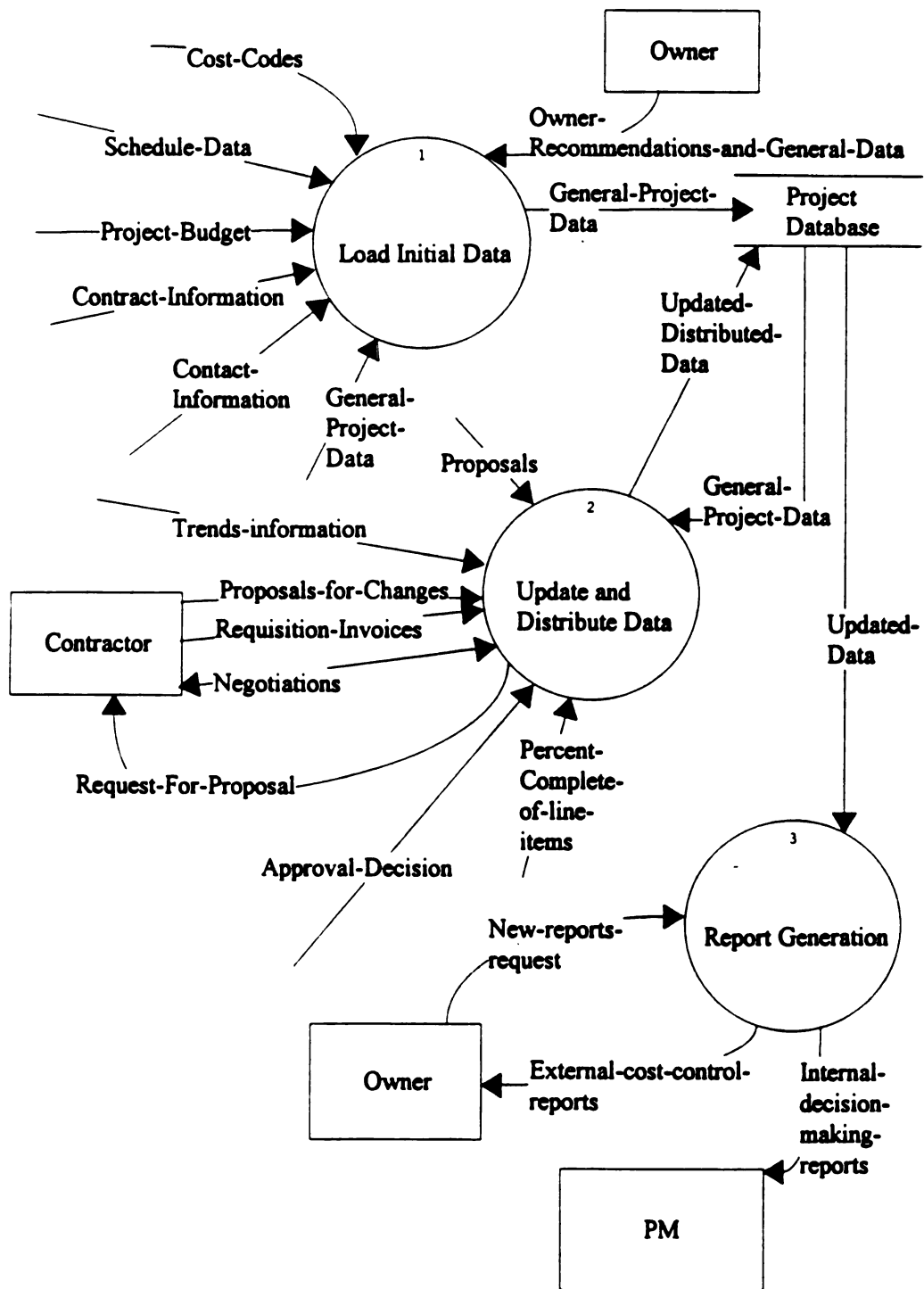


Figure. 5.8 Cost Control System Domain: DFD

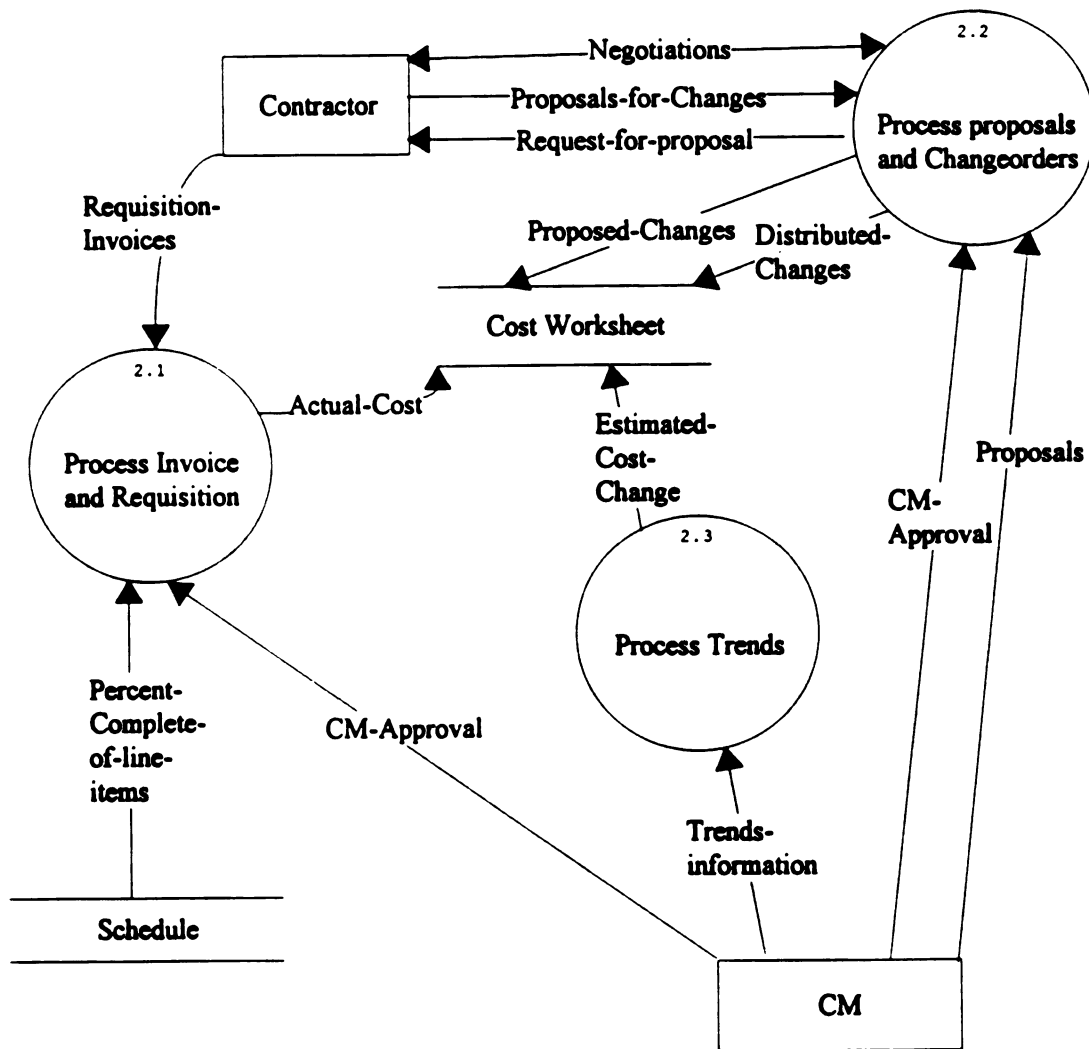


Figure. 5.8.2 Cost Control System-" Update and Distribute"

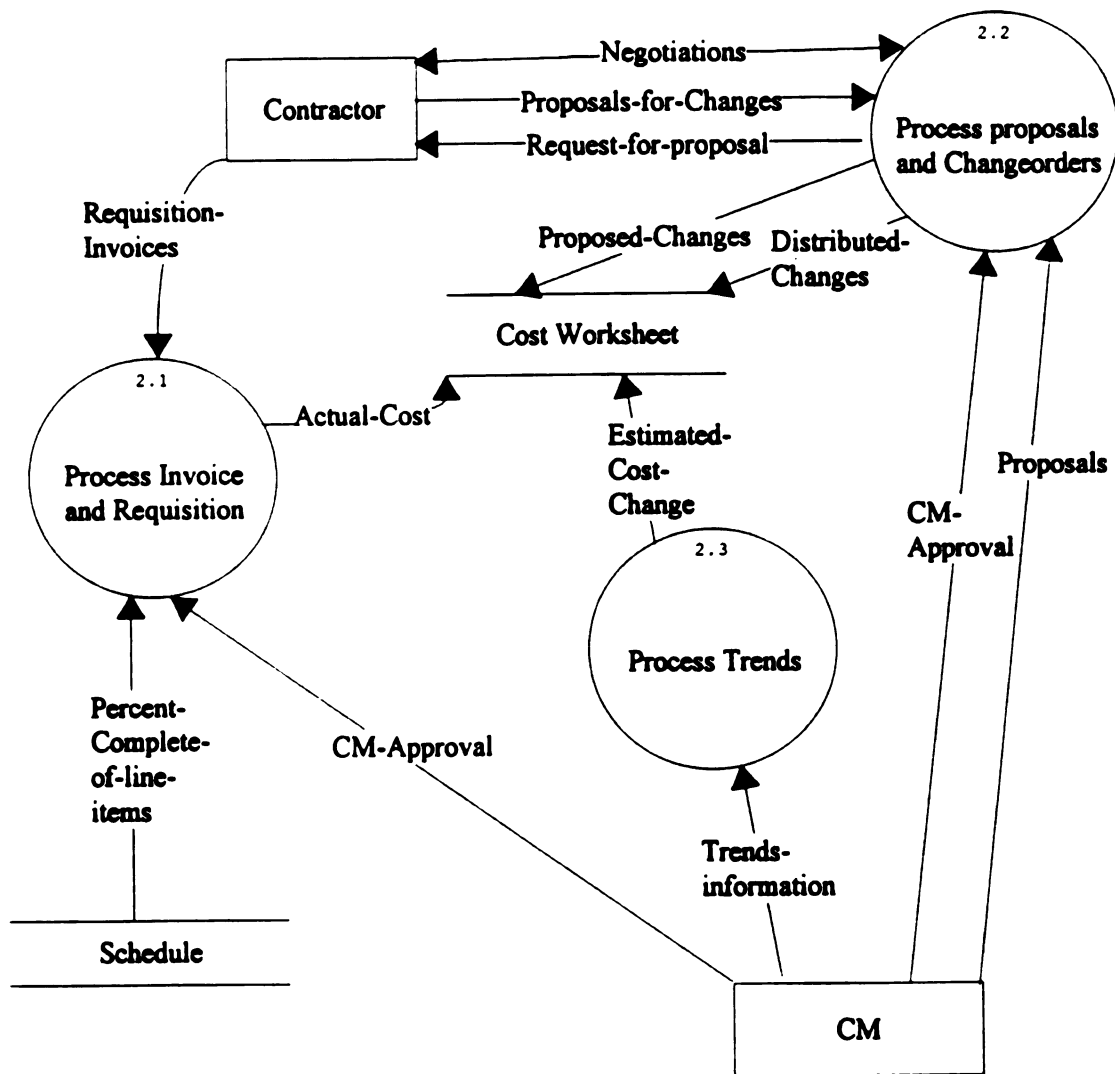


Figure. 5.8.2 Cost Control System-" Update and Distribute"

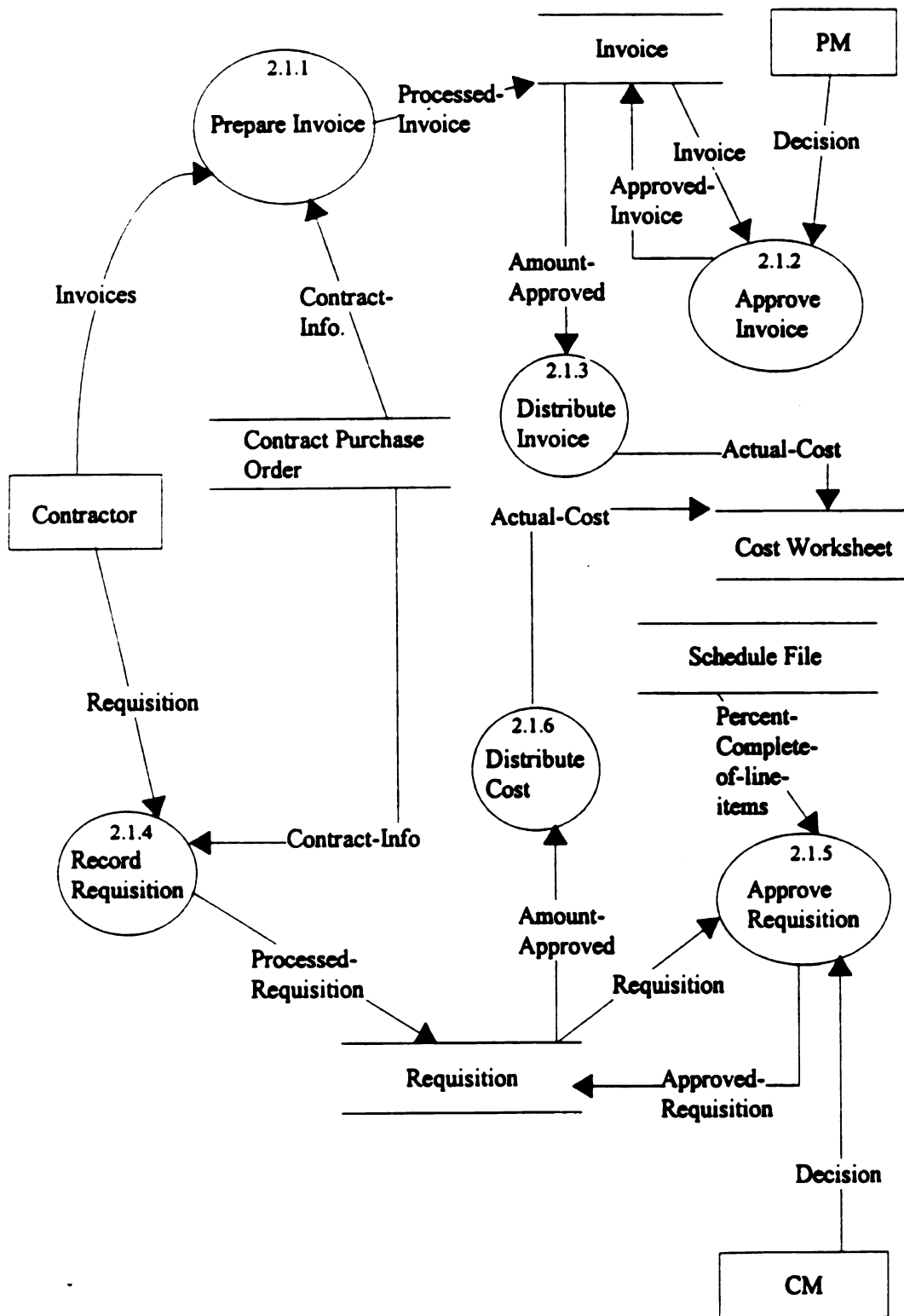


Figure. 5.8.2.1 Cost Control System-" Process Invoice and Requisition"

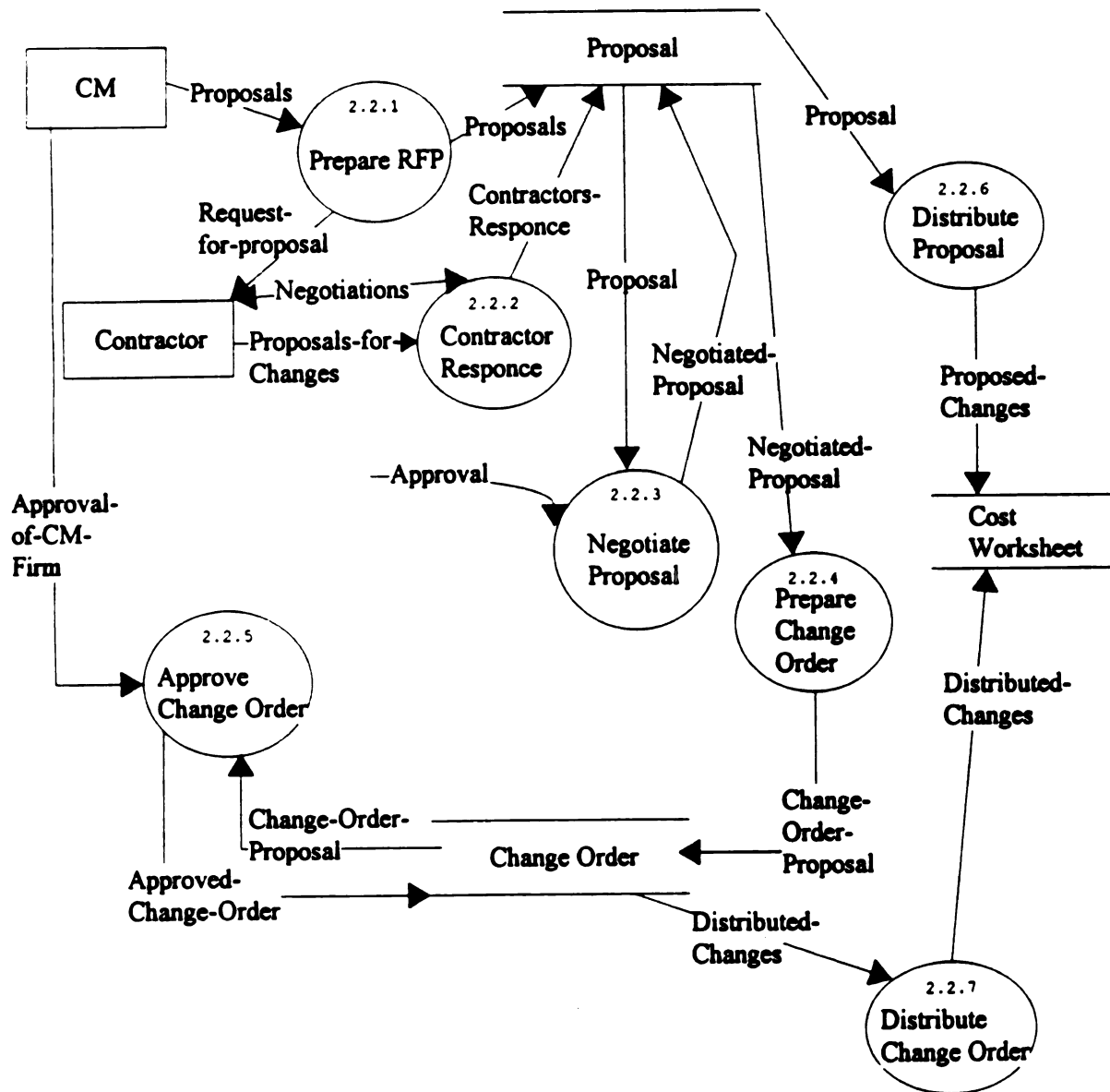


Figure. 5.8.2.2 Cost Control System-" Proposals & Change Orders"

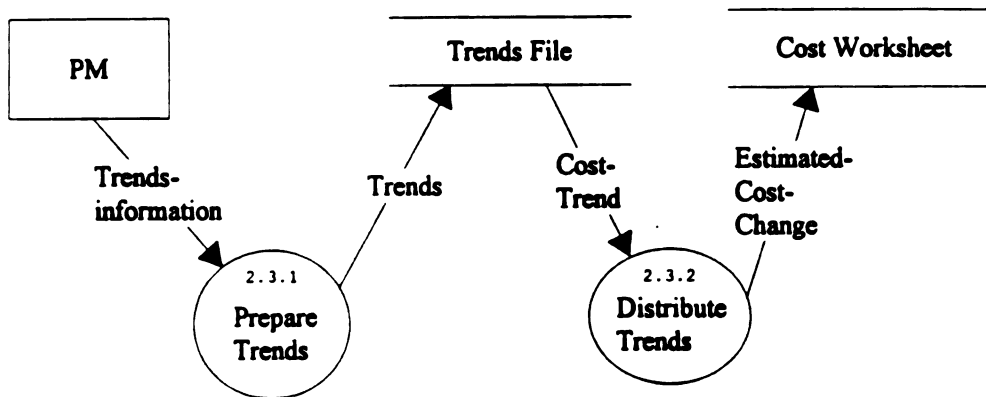


Figure. 5.8.2.3 Cost Control System-" Process Trends"

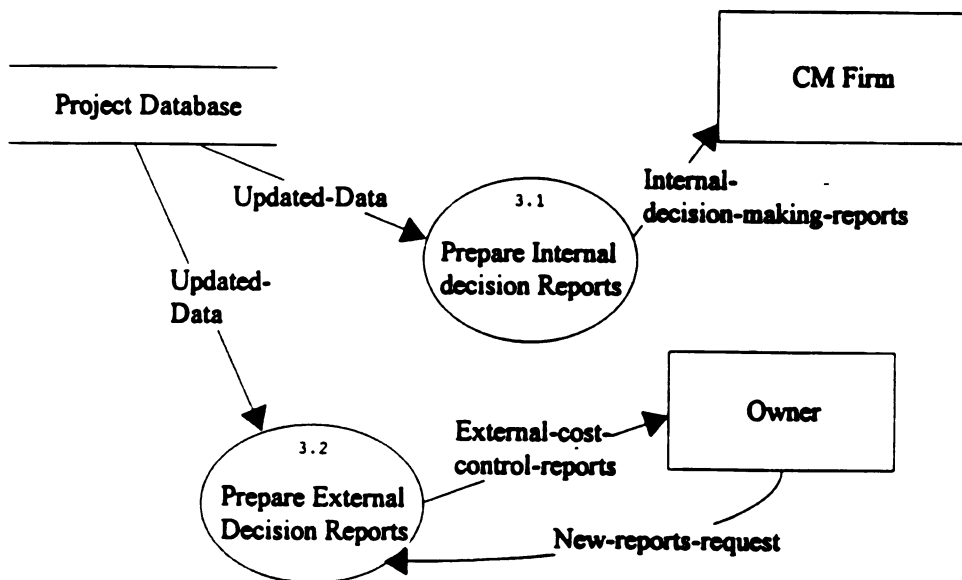


Figure. 5.8.3 Cost Control System-" Prepare Reports"

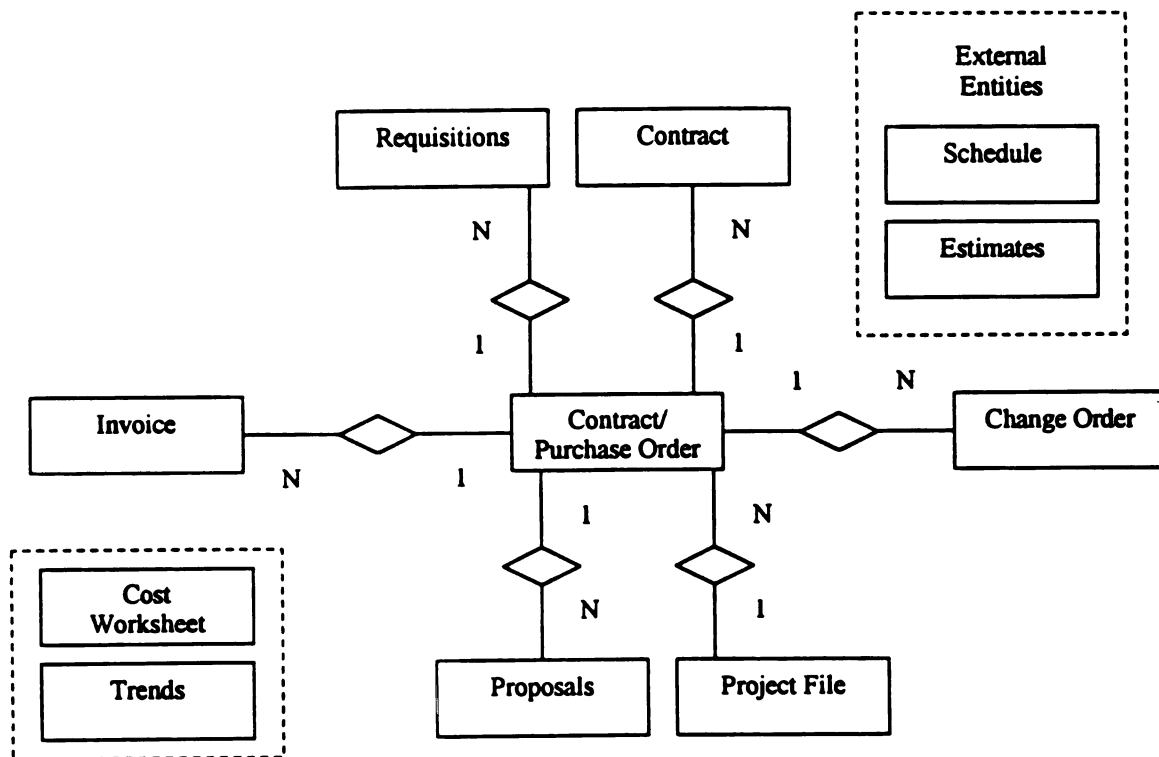


Figure.5.9 Data Model of Cost Control System

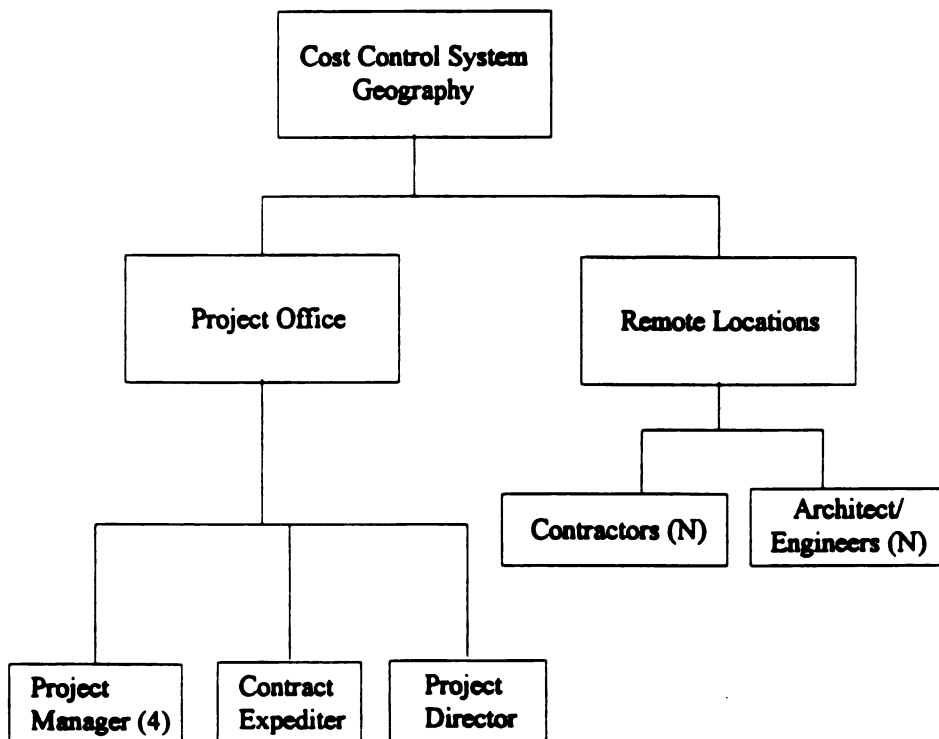


Figure.5.10 Network Decomposition Diagram

Table 5.4 Data Flows, Events and External Agents in ERDs

Dataflow	Explanation
Project budget	Budget information is added from the estimation system to corresponding contracts
Proposals	Proposals are invited from contractors in case of change in construction scope
Trends information	CM firm may document trends to note possible changes in cost of project.
Contact information	Information about all organizations involved in the construction contract
Internal decision making reports	Reports generated for decision making by the CM firm
Owner recommendations	Owner recommendations about scope and requirements of the cost control system
External cost control reports	Reports sent to owner
Proposal for changes	Contractors' reply to the proposals sent by the CM firm
Approval decisions	Approval of proposal or change order by the CM firm
Contract Information	Contract related financial and general information
Cost codes	Codes at which cost is monitored. Cost is distributed into these codes from all other cost entities such as contracts, invoices, requisitions, change orders, proposals
Schedule data	Data transferred from scheduling system such as start dates, finish dates, and percent complete of the activity.
New report request	Owners may ask for new reports
Requisition invoices	Contractors sent requisitions and invoices periodically to the CM firm for their approval
Request for proposal	Proposals sent to contractor for review and reply

Table 5.4 Data Flows, Events and External Agents in ERDs (Continued)

Processes	Explanation
Load initial data	This process includes processes such as initiation of project, loading general project data, loading organizations involved in contract and contract information, loading cost accounts and scheduling information.
Update and distribute data	This process consists of 3 sub processes: A. Process invoices and requisitions: This includes accepting invoice and requisition from contractor, approving invoice and requisitions and distributing them to appropriate cost accounts. B. Process proposals and change orders: This includes sending proposals to contractors, receiving contractor responses, negotiating and approving proposals, initiating fresh change orders or from approved proposals, approve change orders and distribute proposals and change orders to the cost work sheet. C. Process trends: Prepare trends and distribute trends to appropriate cost accounts.
Generate reports	This process includes processes such as generation of internal reports for decision making and external reports for owner or other external agency.

External Agents	Explanation
Contractors	Number of organizations contracted by the owner for various kinds of work
Owner	Owner of the facility for which construction is performed
PM	Project Managers who manage and use cost control system
CM	Construction Management organization in charge of managing construction aspects of the project.

Table 5.5 Entities in E-R Diagram

Entities	Attributes	Example
Contract/ Purchase order	Contract #	A0001
	Contract To	Sitework Contractor
	Contract From	Owner
	Amount	\$ 30,000
	Description	Sitework related to building and utilities.
	Start Date	15 January, 1999
	Finish Date	15 March 1998
Project	Name	BLDG
	Title	Building Project
	Location	East Lansing, MI 48823
	Description	Construction of two story research laboratory
	Start Date	1 January 1999
	Finish Date	1 June 2001
	Owner	Michigan State University
	CM	Construction management Consultants
Schedule Data	Activity ID	10100001
	Description	Clear topsoil
	Start Date	1 February, 1998
	Finish Date	4 February 1998
	Percent complete	50
Contact	Contact ID	STWK
	Company Name	Sitework Contractors
	Address	1, Spartan Spirit, East Lansing, MI 48823
	Tax ID	10-558-6532
Invoice	Invoice #	001
	Contract #	A0002
	Date	1 February 1998
	Title	Purchase of dewatering pump
	Amount	\$4,000
	Check #	2345167
	Amount paid	\$4000

Table 5.5 Entities in E-R Diagram (Continued)

Requisitions	Application #	0001
	Contract	0001
	Date	30 Jan 1998
	Description of work	Clearing site
	Schedule of values	\$3000
	Previous application	0
	Work done this period	\$2500
	Material stored on site	\$0
	% work done	83.33%
	Retainage	10%
Proposals	Proposal #	001
	Contract #	0001
	Date	1 Feb 1998
	Description	Dewatering of foundation
	Proposed amount	\$5000
	Negotiated amount	\$4500
Change Order	Change Order #	0001
	Contract #	0001
	Date	15 Feb 1998
	Description	Dewatering of foundation
	Amount	\$4500
Trend	Trend #	001
	Description	Possible increase in gas price
	Amount	\$20000
Cost Worksheet	Cost Account	010101
	Description	Building related sitework
	Original Budget	\$50000
	Approved Revised Budget	\$5000
	Pending Revisions in Budget	\$2000
	Estimated Revisions in budget	\$0

Table 5.5 Entities in E-R Diagram (Continued)

	Original Commitments	\$45000
	Approved Revised Commitments	\$4500
	Pending Revisions in Commitments	\$0
	Estimated Revisions in Commitments	\$0
	Actuals Received	\$0
	Actuals Issues	\$3000

Build discovery prototypes: Construction managers have a very good idea about the information needed. Unfortunately, some may not know all of the information that is possible to be obtained through a construction management cost control system. Therefore, discovery prototypes using prototyping tools such as MS ACCESS may be used to verify and update user requirements. Prototyping is a good approach for identification of unique user interface requirements.

Prioritize CMCC requirements: Based on the construction management cost control requirements identified in previous activities, the following priorities are developed. These priorities may be used if the project lags behind the target.

- The first priority is for a functional cost control system which can manage cost related documents like contracts, purchase orders, change proposals, change orders, invoices, and requisitions. This system should distribute data in the required cost account format and develop predefined reports.

- The second priority is that the system should try to handle material delivery documents and the documents showing probable trends in project cost. The system should have multiple access, which can facilitate online data entry. The system should also have links with scheduling system
- The third priority is to get remote access to the system so that contractors and suppliers can access the system. Reports should be generated and posted online so that all the project participants including the owner can access the reports.

Modify Project Plan and Scope: The system analyst should negotiate scope, schedule and budget after understanding the detailed scope of the project.

5.4.4 CMCC system configuration phase

In the configuration phase, different technical alternatives are explored to achieve system requirements.

Define candidate solutions:

Table 5.6 shows the three possible solutions for a cost control system. The rows represent different features whereas the columns represent three candidate solutions. These solutions are organized side-by-side to compare different features so that these can be used to identify a target solution.

Table 5.6 Candidate Solutions for Cost Control System.

Characteristics	Candidate 1 Stand-alone Commercial Package	Candidate 2 Networked Commercial Package	Candidate 3 Networked Custom Made System
Computerized System	Commercially available solution would be purchased and customized to project requirements. Would work only on one workstation	Commercially available solution would be purchased and customized to project requirements. Would work on client-server environment	Customized client-server system will be developed using application development tool such as MS Access
Benefits	Can be implemented quickly because it's a purchased solution	Same as 1 & client-server computing gives online access to system data.	Customized solution according to project requirements.
Server & Workstation	High-end : Current technology. <i>Eg.</i> Pentium II workstation with windows 95 installation	High-end : Current technology. <i>Eg:</i> Pentium II, MS Windows NT class server and Pentium II, MS Windows NT workstation	Same as 2
Software Tools	MS Access to provide customization of package to provide report writing and integration.	Same as 1	MS Visual Basic with MS Access for developing client-server application.
Application Software	Package Solution	Package Solution	Custom Solution
Method of Data-Processing	Batch processing on stand-alone workstation	Client-server	Client-server
Output Devices and Implications	A laser printer	Networked Laser printers	Networked Laser printers
Input Devices and Implications	Keyboard & Mouse	Same as 1	Same as 1
Storage Devices	Hard disk required memory and zip drives	Server storage	Server storage

Analyze Feasibility of Alternative Solutions:

Based on the solutions identified, a cost-benefit feasibility analysis is conducted and a feasibility matrix is developed to compare three solutions identified in previous step. Table 5.7 shows the feasibility matrix. Rows in this table represents the four feasibility criteria where as the columns represents the candidate solutions.

Recommend a system solution

On the basis of the feasibility matrix, solution 1 does not satisfy many system development objectives even though it's the most inexpensive and fastest to implement. It may be noted that those who try to develop systems without going through system development methodology tend to go for quick and dirty solutions. Such a stand-alone system cannot satisfy the system objectives for a large commercial construction project. Therefore, the system analyst has to look for a networked solution.

The basic difference between solutions 2 and 3 is that one solution promotes custom system development while the other is based on a ready commercially available solution.

Technical feasibility: Normally in the construction industry it is difficult to find people with skills who can build customized applications on system development platforms like MS Access. Also, it is very difficult to find experienced users who can manage and develop custom reports in these environments.

Table 5.7 Matrix of Feasibility Study

Feasibility Criteria	Candidate 1	Candidate 2	Candidate 3
Operational Feasibility	This will result in a greater delay in system status and actual status. All the users will not get access to data	Fully support user required functionality by customization efforts.	System developed according to the unique project requirements.
Technical Feasibility	Need to hire and train system operator with ready commercially available solution. Plus need expertise to customize commercially available product.	Need to hire and train system operator with a ready commercially available solution. Plus need expertise to customize commercially available product.	Need to have very high system development skills in developing environment. Users need to have some amount of skills in that environment.
Economical Feasibility	Least expensive	Moderately expensive	Most expensive
Schedule Feasibility	Least time	Moderate time	Maximum time
Most Feasible Environment	Small project with single project manager	Medium to large size project with typical system requirements	Large size projects with unique system requirements

This may also lead to having a very high level of involvement of the system analyst during the support phase, which may result in high system maintenance cost.

Operational Feasibility: In case of projects with unique requirements, it may be difficult to customize the commercially available solution. But for most of the typical construction projects, commercially available solutions can be customized to satisfy all operational requirements.

Economical Feasibility: It is generally less expensive to buy a ready solution compared to building it from scratch. The cost of building a new custom solution includes the cost of the development platform, system analyst's time, training and user's training on the development platform. These systems cannot be used in other projects as they are made according to the requirements of the specific project. The ready commercially available solution is comparatively inexpensive and takes time only to customize according to the requirements. The expertise developed in one project can also be used in other projects. The same product can be used for future projects. Also a fair number of people may already have knowledge about the software package which would help in the recruiting purposes.

Schedule Feasibility: Ready packages take very little time compared to custom-made systems. Therefore, considering all these factors, commercially available ready software packages which can satisfy all operational requirements are a better alternative for a construction project environment, unless the project requirements are unique.

After identifying the system solution, a formal presentation should be made to the project director and the user team about the details of the target solution. A written system proposal should include all the outputs in the configuration phase with details of the recommended solution.

5.4.5 Procurement Phase

Research Technical Criteria & Option:

In this activity, different options are identified on the basis of the recommended system architecture. In the CM contract delivery system, the owner reimburses all expenses for the system development. Therefore, some constraints may exist about the vendor from whom all the software and hardware can be purchased. The system architecture can be divided in terms of hardware and software.

Hardware: The hardware part of system architecture includes a server, workstation and networking. The workstation and server hardware should be selected to support data requirements. A tradeoff between features offered by the hardware and money spent for that should also be studied while selecting the hardware configuration.

Networking: After identifying the networking requirements and designing the network configuration, a networking consultant can be employed to do the required wiring.

Software: The system analyst needs to identify the technical criteria for selecting the commercially available cost control system.

The following list illustrates the technical requirements for the cost control software:

- Should be able to manage all contract documents.
- Should be able to develop cost codes and distribute costs to these cost codes.
- Should have a customizable environment.

- Extensive reporting features including a custom report writer.
- Should work in a client-server environment.
- Should have good security features.
- Possible integration with Primavera scheduling software.

Based on these criteria and an industry survey on the cost control system, two software packages are identified as possible solutions. Possible vendors are also short-listed.

Solicit proposals from vendors:

After identifying the product options, technical criteria and possible vendors, proposals are invited from the short-listed vendors. For the hardware part, quotations are invited based on the required specifications. For the software part, a list of technical criteria is provided to the vendors and they are asked to supply their proposals satisfying these criteria.

Validate vendor claims and performance:

Considering the limited time available for developing information systems in a construction project environment, it may be very difficult to go through the proposal validation process. Consequently, the cost control software is often selected based on past experience both within the firm and from interviews with other users. If no experience is available about a product, then it is generally better to go for a well-tested product than an experimental one. Vendor

proposals, demonstration packages, manuals, and consultation with other users can be used to solicit vendor claims.

Evaluate and rank vendor proposals: After validating the vendor proposals, all proposals will be ranked on factors such as the features provided, costs of the products, licenses for multiple copies, technical support, and training. A cost control system such as EXPEDITION developed by Primavera Systems Inc. may be recommended based on the features provided by the software. The project director makes the final decision after recommendations.

Award contract: A contract will be awarded on the basis of ranked product proposals. Negotiations with vendors would include issues such as technical support, training and site licenses, which can be used for other projects.

Establish Integration Requirements: This activity includes development of requirements for integration between EXPEDITION, a contract control software and Primavera project planner (P3), which is a scheduling system.

- **Data transferred from P3 to EXPEDITION:** Various cost documents such as contracts, purchase orders, change orders, proposals share start and finish dates with the scheduling activities. The line items in the requisition collect the percentage work done from the corresponding activity in the scheduling system.

- **Data transferred from EXPEDITION to P3:** P3 accepts cost related data such as budgeted cost and actual money paid to the contractor from the requisition line items.

For using EXPEDITION and P3, one needs to make some early decisions. One of the decisions is to have identical cost accounts so that data can be transferred and compared against similar codes.

5.4.6 Design and Integration Phase:

The design phase is mainly focused on customization of commercially available solution to the project requirements.

Design networks: The network is designed based on the network connectivity diagram, selected system architecture and geographic requirements of the system users. Network design includes network topography and network component design.

Analyze & distribute data: Considering the two tier client-server architecture, all data will be stored on the server and can be accessed from connected workstations.

Analyze and distribute processes: After identifying the network layout, system processes need to be distributed to fulfill network requirements. Figure 5.11 shows the network topography and the corresponding distribution of data and

processes. Rounded rectangles in figure 5.11 represent the central project job site server and workstations of system users. The PRIMAVERA AND EXPEDITION systems are stored on project server.

Analyze Software Data-structure: Due to the application of a ready package no database design is required. Nonetheless, the system analysts need to understand the underlying data structure and identify whether or not the data elements satisfy the entire systems requirement. If some data requirements are not satisfied by the commercially available solution, then custom data items should be designed. These custom data items can be added to the existing data structure and can be used during report generation. The underlying data structure can also be used for custom report generation using report-writing tools.

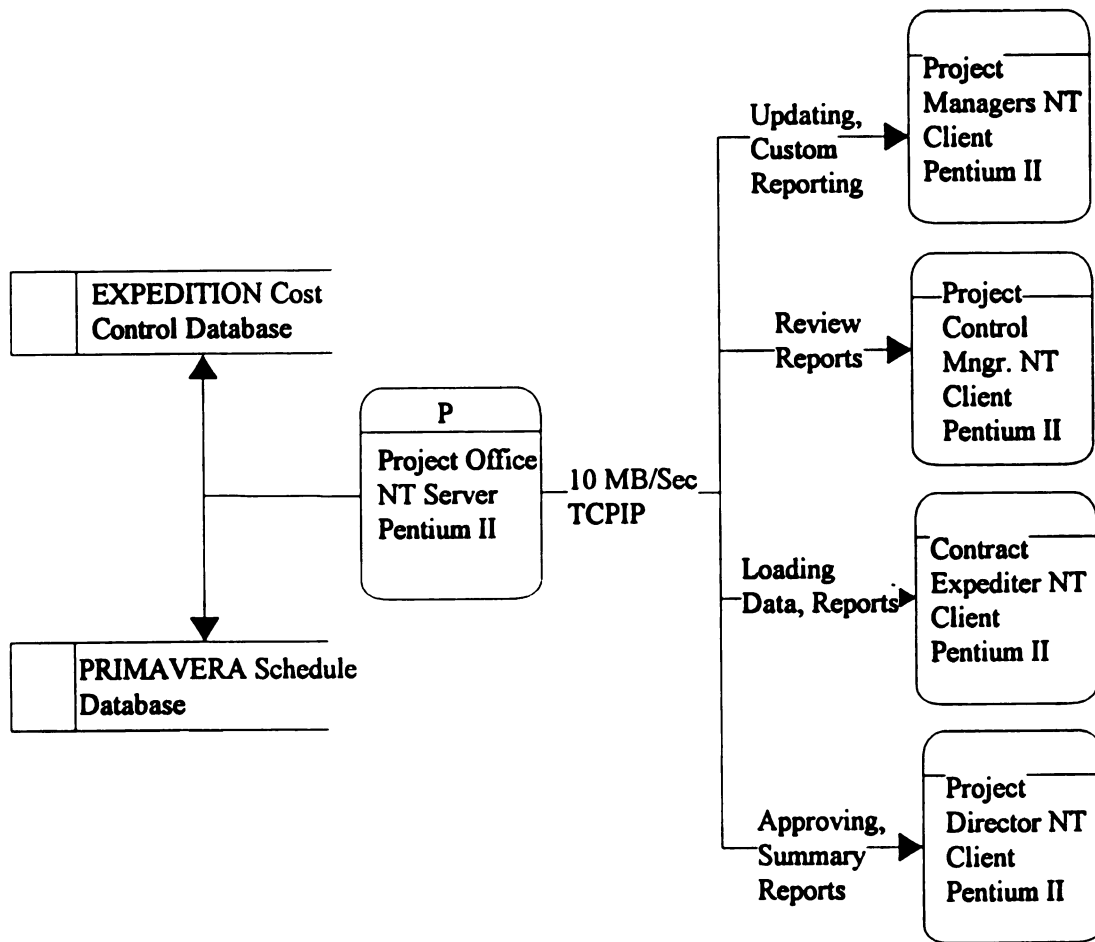


Figure 5.11 Data and Process Distributed Network Diagram

Design Computer Input & Output:

Computer Inputs: Design of the computer inputs consists of two components. The first is the data capturing mechanism. Considering the client-server architecture, the data capture mechanism is on-line data entry. This method encourages entering the data in the system as soon as it is generated. Therefore, all system users are expected to enter relevant data in the system as soon as possible. Another part of data entry is the source document, which is used to capture data from its source. This is normally a form in which data is stored and then processed into the system. The system analyst needs to design forms to collect information about cost related data items such as change orders, change proposals, requisitions and invoices. It is generally better to design forms which are in the same format as the screen layout. Therefore, the source documents designed should be identical to the data screen display forms of the EXPEDITION software.

Computer Outputs: The first step is to identify the system outputs. The system outputs of the cost control system are the reports developed from the system. These reports are of two types. One is an internal report and the other is external. Internal reports are meant for the project director and the project managers as decision support tools. External reports are meant for the project owners or other external organizations such as financial institutes. Reports can be of a tabular or a graphic nature. Graphic reports are developed especially for higher management. The following list illustrates possible reports.

A. Detailed reports: The cost control system needs to develop detailed reports of various cost items. Examples of detailed report are details about a particular contract, invoices, purchase orders, change orders, and proposals related to that contract. Such reports can help the project manager get an overall understanding of the status of that contract.

B. Summary reports: The most important summary report for the cost control system is the report explaining the budget, amount committed, and the actual money spend for each cost account. The project director can use this report to analyze performance of the whole project.

C. Exception reports: These reports can be generated only for those contracts which show considerable variances. This helps upper management to concentrate only on contracts which need special attention. This report can be developed on the basis of variances.

D. "Ad Hoc" reports: These are generated based on the situational requirements and therefore, they cannot be planned beforehand. But report designers need to identify the way of generating these reports using a report writer or opening a database in a reporting environment such as MS ACCESS.

External reports include the reports sent to the owner, and to external agencies such as banks. These reports are predefined by the CM firm and the external agency, and generated periodically according to the predefined format.

After identifying the contents of the reports, the system analyst needs to identify the medium and format of these reports. Reports printed on paper are considered a standard format for preparing reports. Reports can also be

published on the intranet. This can reduce paperwork, give instant access to all the project participants including owner access to the project information and this will represent the status of the project close to reality. But intranet development and management involves cost, and firms need to have expertise for developing an intranet. Also after developing a project intranet, someone needs to manage it and update the reports. Therefore, this activity gets least priority and project intranets are developed after the whole cost control system is developed.

To identify report format, some prototype reports may be developed using prototyping tools like MS EXCEL. After identifying the reporting format, the system analyst needs to check if EXPEDITION can develop reports in that format with those contents. If not, customized reports need to be developed to satisfy the reporting requirements. Designing reports is an iterative process where more reports are developed and original designs are changed.

Present & Review Design: Present deliverables from the design phase and develop a schedule for the next project activities.

5.4.7 Construction phase

After designing the system, the next step is to construct different components of the system.

Build and test network (Hardware): The first activity is to develop the network. Network development depends on whether the owner is providing cabling and a

server facility. In case of an absence of any networking facility, the system analyst needs to start this activity with delivery and installation of a server and workstations. The network operating system is installed on the server and client machines and the cabling is done. Then the network is configured and tested for connectivity, access and security.

Install, customize and test new software package: After developing the network, commercially available software is installed on the client and server ends. The software is tested for network connectivity, data sharing and data access. Software is configured for multiple access. Custom reports are developed in EXPEDITION. For more complex reports, the report writing tool provided with EXPEDITION software "Crystal Report Writer" is used to construct custom reports.

5. 4.8 Delivery Phase

Conduct system test: After installation, customizing and testing individual pieces, the whole system is tested using test data. It is preferable to have test data from the same project or a similar project.

Prepare conversion plan: The conversion plan is critical for the successful completion of the development process. The conversion plan identifies the way of populating the application with data, end-user training, documentation and the actual start of application usage. The project team is also given an opportunity to

test the system and to accept or reject a system before actually starting to use it in the project.

Install database: The application software is populated with the project data. This data includes contact, contract, and purchase order information. The budgeted and committed costs are distributed to the cost codes. Also, other kinds of data such as general project information, all organizations involved in the project, and schedule related information are loaded.

Train system users and prepare documents: Training and documentation are essential for a successful implementation. Training can be offered in-house to all project team members. Some system users, such as the contract expediter who manages and maintains the system, may get training from the software manufacturer because these people become responsible for day-to-day problem solving. The system analysts should train all other users in the group. The documentation often contains user references provided by the system manufacturer. Unfortunately, these reference books are not written from the user's perspective and normally users don't want to search these manuals. Therefore, a working document should be prepared which can guide users in a step-by-step fashion for performing their task. Separate documentation should be prepared for project managers and the contract expediter according to their interaction with the system.

Convert to new system: After completing the training, system users are asked to use the system, and start updating and reporting cost related data. System analysts should meet with all users, more frequently initially, to discuss issues related to the application of the system, and the system development process. This feedback can help clear up any confusion over the use of the new system, and also help the system analyst in developing future systems.

5.4.9 System Support

After finishing the development process, the system analyst generally presents all documentation developed during the system development process to the project owner and gets the system approved from the project owner. The system analyst should provide support for solving all future problems. The system analyst may now start the second phase of the system development project, consisting of lower priority features such as providing remote access to the project team members and development of the project intranet. If new system requirements are observed in the future, then a request needs to be made and the system analyst should follow all phases and activities of CMSDM.

5.5 Summary

This chapter demonstrated the application of CMSDM in a project environment managed by a construction management contract administration system for development of a cost control system. The cost control system is developed using CMSDM making appropriate changes according to the project and system

variables. This cost system is only in a model format and can be implemented physically if required. The purpose of this chapter was to demonstrate the application of CMSDM and understand the phases and activities involved in system development.

The next chapter consists of two case studies where a system development process used in industry for developing a cost control system is tested, evaluated and compared with CMSDM.

CHAPTER 6

CASE STUDY

6.1 Introduction

This chapter applies and evaluates the CMSDM in two actual construction project management information systems. Two construction projects managed by CM contract delivery systems were selected and the cost control systems used in those projects were analyzed. The system development methodology applied by the construction organizations was also examined. This methodology was understood through interviews with the developers, users and system owners of the organizations. After identifying the systems development process and the existing cost control system, the process and product were evaluated based on the CMSDM and the developed cost control system. Industry professionals were requested to evaluate the CMSDM and its possible applications in real project environments.

This chapter is divided into two sections, one for each case study. Each case study includes an introduction, the system development process, the cost control system, features of system development and possible application of CMSDM.

6.2 Case I: Program Management Project

Case I is a project financial tracking system for a project being coordinated by a program manager. This system is called Bid Pack Financial Tracking Log

(BPFTL). This project consists of deferred maintenance work for a school district. The school district has about 40 schools, which are on an average 100 years old. Therefore, the school district floated a bond program for financing the deferred maintenance of the schools. The bond program was for \$ 135 million, and it was successfully funded through different investment agencies. The school district developed an estimate of all required deferred maintenance work for all of the schools through a consulting firm. The school district then employed a CM firm to manage the bond management program. The CM firm is acting as a program manager and its duties include managing finance, design, document preparation, bidding and the construction process. The CM firm reports to the facilities department of the school district.

After identifying the total estimates of required deferred maintenance work, all work was prioritized and the CM firm decided which maintenance work should be included in the bond management program. After identifying the scope of the work under the bond management program, about 90 bid packs were developed for managing construction. All of the bid packs were divided among the project managers who managed their corresponding bid packages independently. Each project manager manages around 10 to 15 bid packs consisting of about 10 schools. The scope of the work varies from replacing windows to adding classrooms. Each project manager was initially managing individual bid packs on a spreadsheet according to the project requirements. But a need was observed to manage and store the progress of all bid packs in a central database environment to monitor and control progress of the bond

management program. This need triggered the development of the BPFTL system. The facilities department of the school district is the construction project owner, the project director of the CM firm is acting as system owner and all project managers of the CM firm are system users.

6.2.1 System Development Process

After identifying a need for a financial tracking system for the bond management program, the system owner and the system users had brain-storming sessions to identify the system requirements. System requirements were identified based on reports required for decision-making. A system support request was filed with the regional project support group. Figure 6.1 shows the system development process. The following list includes the salient points of the system development process employed by the system analyst.

- The system scope was not defined with respect to the budget and schedule.
- No time was spent on understanding the generic cost control system.
- User requirements were not represented by any modeling technique.
- Data input screens were designed without much user input.
- Users were not provided enough training.
- No system documentation was provided.

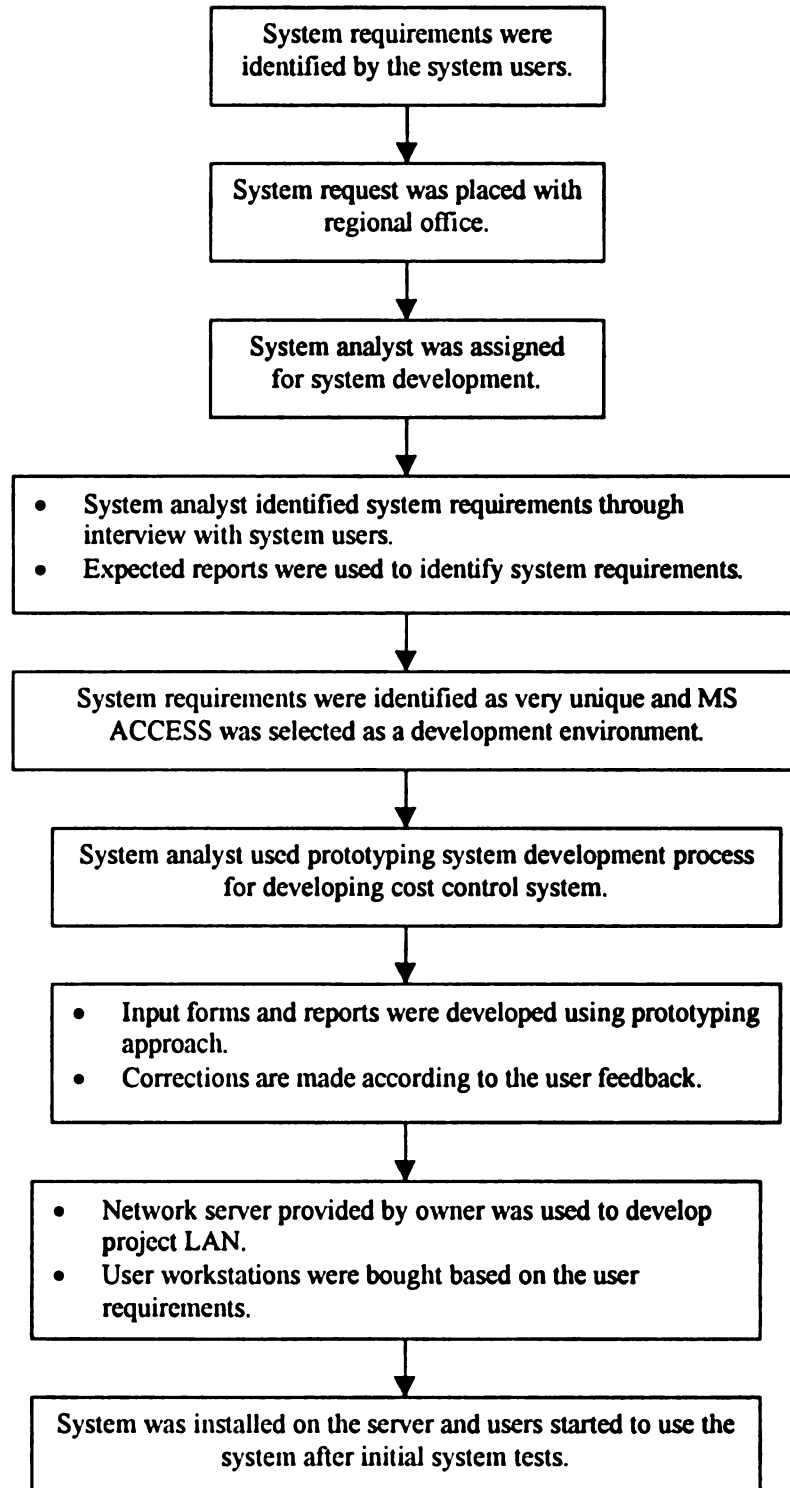


Figure. 6.1 Case I: System Development Process

The absence of training did not have a significant effect initially because all users at the time of system implementation were also involved in system development and had a good idea about the system structure and processes. During the course of the project, users were replaced and some new users were added to the project team. Due to the lack of training, documentation and a user-friendly system, new users had considerable difficulty in using the system. Also, some users identified new requirements for the system, and initiated a system revision, the system again went through a development process. Even though this new revision did not contain a lot of changes in the basic data structure, it made it difficult for system users to comprehend the system in totality and to make use of the system for decision making due to continuous changes and the testing process. An external system developer was used for the system modification. The project owner found the local system developer to be better from the time, cost and efficiency point of view. Some system users drew diagrams in the form of flow charts to show processes and user navigation within the system to the system developer. This resulted in a change in the system and it remained under construction.

The following section describes the processes involved in the BPFTL by using data flow diagram as explained in appendix A, and in the BPFTL data structure by using an entity-relationship diagram as explained in appendix B.

6.2.2 System Data Model and Process Models

The processes involved in the BPFTL system can be described most efficiently by using a data flow diagram. The data stores represented in this data flow diagram are used to develop an entity relationship diagram which represents relationships between these data stores.

A. Process Model:

This system involves five main processes.

- **Load program data:** This includes loading initial project related information such as list of schools, architects, contractors, project managers and different project phases.
- **Load bid pack data:** Prepare change orders: This includes loading information about individual bidpacks.
- **Update proposal request:** This includes receiving proposals from the contractors and negotiating a price for the change in scope of work.
- **Prepare change orders:** This includes preparation of change orders.
- **Prepare reports:** This includes producing internal reports for decision making and external reports according to owner requirements.

Figure 6.2 shows the data flow diagram for BPFTL system.

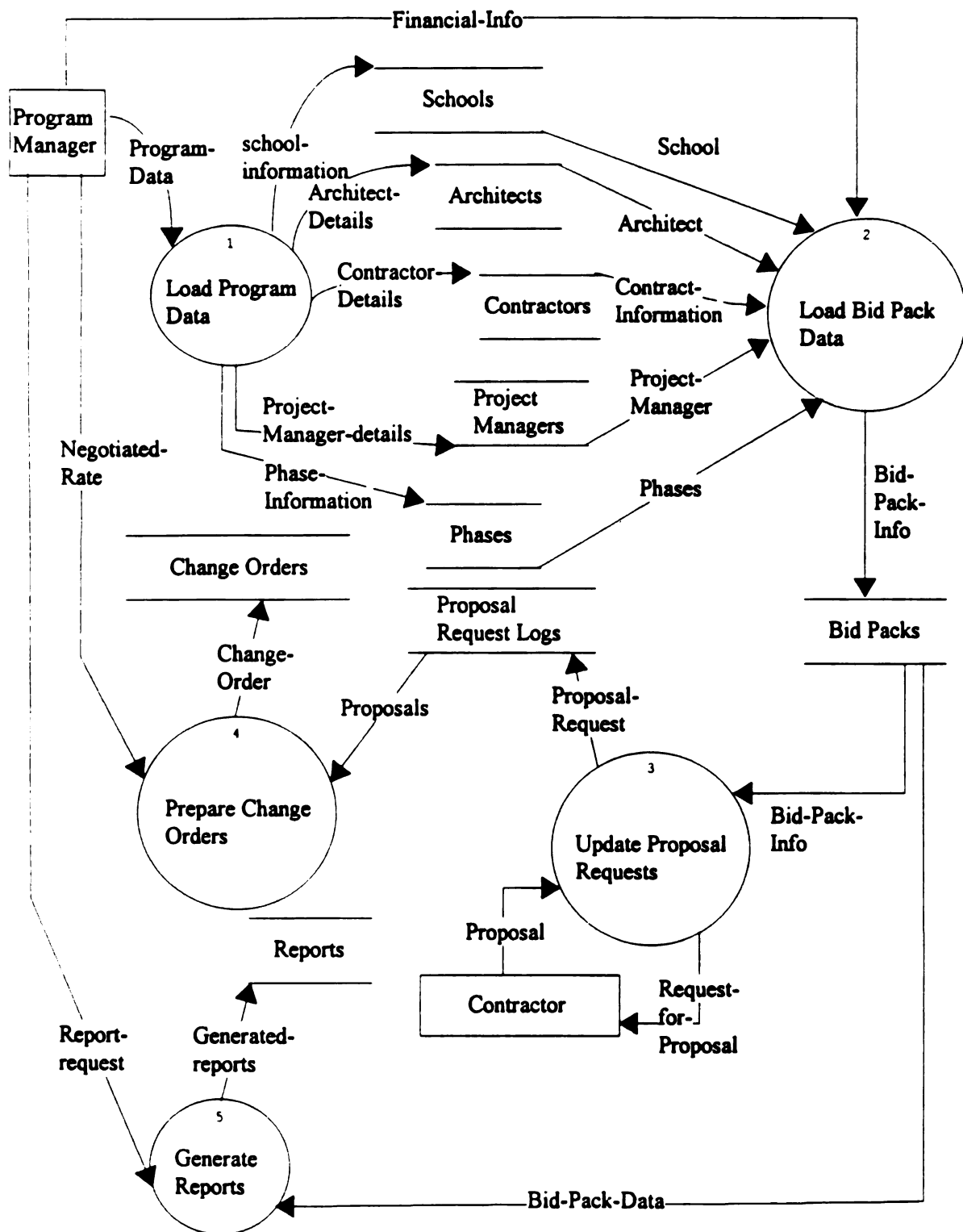


Figure. 6.2 Data Flow Diagram for BPFTL System.

B. Data Model:

The underlying data model of the BPFTL system is represented using an entity relationship (E-R) diagram. Figure 6.3 shows the E-R diagram for the BPFTL system.

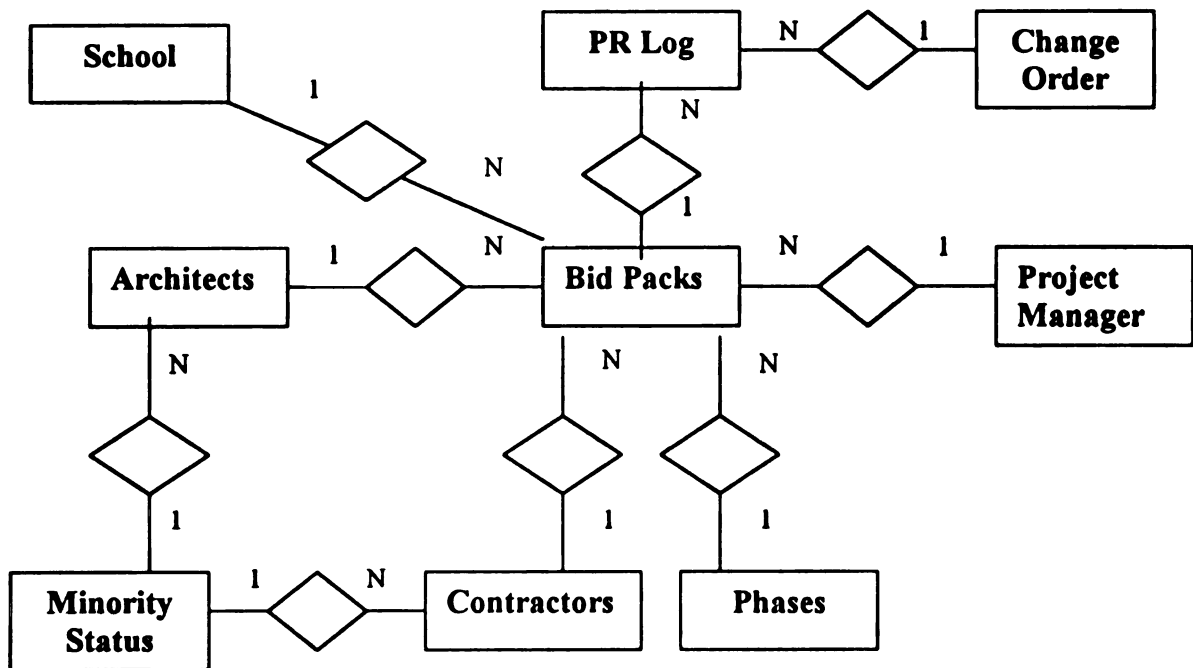


Figure 6.3 Data model in BPFTL system.

C. Cost Control Reports

Table 6.1 shows the financial analysis screen for one of the bid backs. This screen shows the cost control analysis done by the system for an individual bid packs.

Table 6.1 BPFTL: Financial Analysis Report for Individual Bid Packs

<i>Burroughs</i>		<i>Tuckpointing</i>	
Project Manager: Cheryl Humann		Actual Amounts	
Architect: Smiley Glotter Nyberg		Trade Shop Scope	\$0
Contractor: McPherson-Towne		Original Contract Amount	+ \$123,539
Phase: 10		Approved Change Orders	+ \$2,122
Original Budget		Current Construction Amount	= \$125,661
Construction Budget	\$135,600	Pending Change Orders	+ \$0
A/E Fees	+ \$13,221	Forecasted Total Constr. Cost	= \$125,661
Soft Costs (excl. A/E Fees)	+ \$3,051	Original A/E Fees	+ \$11,938
OrigContingency	+ \$0	A/E Changes	+ \$0
Total Project Budget	= \$151,872	Soft Costs To Date	+ \$3,069
		Soft Cost Est. to Complete	+ \$0
		Estimated Contingency	+ \$0
		Forecasted Total Project Cost	= \$140,667

6.2.3 Possible Changes in BPFTL due to the application of CMSDM

The previous two sections described the cost control system and the system development process. This section analyzes the system development process and the cost control system in order to evaluate the system development success in this case study. This evaluation is classified in terms of two sections. The first is about the system development process and the second is about the cost control system.

System Development and Management Related Changes

- **Absence of Initial Budget and Schedule:** The initial budget or schedule was not developed for developing the BPFTL system. This lead to the absence of monitoring and control over expenses and schedules during the system development.
- **Absence of well-defined system scope:** The system scope was not defined in relation to schedule and budget. This lack of monitoring and control of expenses and schedule with respect to the system scope may not be possible in tight economical conditions. However, this generally leads to "creeping scope" during and after the system development process.
- **Absence of study phase:** The study phase improves the system developer's understanding of the generic construction management information system, and that helps in understanding the user requirements quickly and comprehensively. Absence of a study phase led to more time in system development.

- **No use of modeling techniques:** Systems developed without modeling the user requirements result in a more time consuming development process, more confusion about the user requirements and about the developer's understanding. It also results in a system without any contemporaneously developed documentation. phase.
- **Prototyping used without modeling:** This results in longer system development time
- **No exhaustive market survey:** No study was conducted to determine if market available software could satisfy program management requirements. Such a study could also help in identifying corporate information system architecture.
- **No comprehensive system test:** This resulted in frequent system failures and in a more time consuming system support phase.
- **Not enough training:** System users were not trained before system installation. System training should be better in quality, should be conducted earlier and should be more in quantity especially for system users with less computer experience and for system users who were not involved in system development.
- **No user documentation:** User documentation helps users in understanding the system. It also helps for new project team members to get used to the system quickly.
- **New changes without training:** System users should be trained for new system changes. This also includes training for new team members.

- **Solicit user requirements and problems during system support phase:**

User requirements and problems should be solicited at the time of making any changes during the system support phase.

- **Cost savings related to system development:**

Considerable extra costs were caused by not following the structured methodology. These extra costs can be divided into two parts.

A. Direct Costs

- Time spent by a system analyst in development efforts.
- Travel expenses including lodging and boarding of a system analyst.
- Expenses incurred on a system analyst during the project control phase.

B. Indirect Costs

- Time spent by project team with system analyst
- Non availability of information
- Time spent to get information by other means
- Possible wrong decisions
- Time spent in trying to solve problems with functioning of the system.
- Prolonged system support phase

Cost Control Related Changes

- **Inaccurate Summarization:** The summarized reports developed for the entire program are artificially generated without considering the detailed

values in the bid packs. Therefore, these reports can be very misleading and the system cannot represent the status of the program correctly.

- **No monitoring of actual expenditure:** This system does not include any provision to monitor actual expenditures on the program. This system does not monitor requisitions submitted by contractors and, therefore, the program management firm cannot check the status of the actual money spent on the program at any time. This also leads to a time consuming process of project managers having to individually use spreadsheets to monitor payments to the contractors for individual bid packs.
- **Inconsistent data redundant activities:** This lack of an interface leads to an information system consisting of various subsystems which cannot share information with each other and cannot show the different stages of project progress. This weakness also leads to a time consuming repetitive updating of two systems.

6.2.4 Evaluation of recommendations and CMSDM by industry

The following observations were made by the industry professionals from the program management project.

- The professionals accepted most of the recommendations related to system development. They observed that all phases and activities involved in the CMSDM would be followed only in large size projects with unique project requirements. Professionals observed a need to have a well developed corporate information system architecture.

- Professionals agreed to the recommendation about user training, documentation and development of a user friendly system for better user involvement in the system.
- The system owner accepted that about 25% of the information system development cost could be avoided by following structured system development methodology.
- The system owner stressed the importance of the support phase while developing an information system for the construction projects. It was observed that all of the initial phases need to be done in a structured manner to avoid a lengthy system support phase which can really take excessive time of the project team. A need was also observed to train one of the users to solve most of the unexpected system performance problems.
- The issues related to the cost control aspect of the system were not fully accepted by the professionals. They noted that the system was developed according to the requirements, and that identification of the system requirements is a very subjective process.

6.3 Case II: Small Scale Construction Management Project

This is a small size construction project managed by a construction management contract delivery system. This project was selected for the second case study primarily to identify the broad spectrum of computer applications in the construction project environment and the system development process employed by this broad spectrum.

Project Facts: This construction project involved construction of an educational classroom building with research facilities, and a construction cost of \$9 million. The CM firm was employed by the owner to manage the construction aspect of the work. The CM firm developed initial estimates on the basis of historical data and the owner's requirements, and on the basis of these estimates, a project budget was formalized. On the basis of this budget, the owner obtained funding for the project. After assurance of funding, an architectural firm was employed to prepare the design documents. The CM firm was involved in some value engineering activities. A detailed project budget was developed after producing more detailed plans. The owner decided to procure this project in a "fast track" method and hence the whole project was procured in three phases including a total of 25 bid packs soon after the design specifications were acquired. After completing the bidding process, the project commitment cost was identified and this commitment cost was used in the cost control operation.

Organizational Structure: The organizational structure includes a project director who looks after a number of small size projects, a project manager who is the main and only decision making entity on the project and a project superintendent, who controls all activities of the specialty contractors. The company decides the project level organizational structure on the basis of the size of the project and the owner requirements. All the day to day decisions are made by the project manager who in turn reports periodically to the project director.

Information System: The organization has a number of small to medium size jobs and is trying to standardize the applications for particular types of functions. They are experimenting with software products such as EXPEDITION and ProLog MANAGER. Presently, no standardized application architecture exists in the organization and the decision about selecting software tools for developing a project level information system is left to the discretion of the project manager. There is no governing decision making body in the organization which is responsible for selecting and developing an information system. The project managers normally use spreadsheets to manage most of the project control operations. The selection of the system depends mainly on the seniority of the project manager and the past experience of the project manager with IT tools.

6.3.1 Project System Development: After taking charge of this project, the project manager identified the reporting requirements and then developed spreadsheets to track and monitor costs related to the project. No other ready software package was evaluated or no one else was involved in development of this system. The project manager has one computer with a laser printer as hardware tools. All system related activities such as system development, data entry, and report generation are done by the project manager. The project manager on this project uses spreadsheets extensively for cost control operations. The progress control is done using ready market software, SureTrak, by Primavera Systems.

6.3.2 Cost Control System

The following is a list of spreadsheets used for cost control operation.

Spreadsheet #1: The first spreadsheet monitors the project level cost such as total budget, total commitments, CM costs, Architect/Engineer (A/E) costs, and cost to complete. This spreadsheet gives a summarized status of the project. This spreadsheet is not linked to the other spreadsheets and data is manually input into the spreadsheet based on the values in other spreadsheets.

Spreadsheet # 2: This includes a summary of cost data for individual bidpacks. This has committed cost, cost after change orders, and the variance between them. This variance column is used to identify the total change in the project cost and individual bid packs.

Spreadsheet # 3: This spreadsheet monitors the proposals received from contractors, negotiated amount from CM firm, decision taken by the owner and A/E, and the final change order amount.

6.3.3 Possible Changes in the cost control system

The following points are observed as possible changes in the system development process if the same system would have been developed using CMSDM.

System Development and Management Related Changes

- For a project of this size, the decisions regarding appropriate selection of IT tools are made by the project managers. Therefore, project managers should be trained and educated with the available IT tools.
- The responsibilities of construction management projects of this size are more or less similar, and, therefore, organizations need to develop an organizational application architecture. This architecture can include appropriate IT tools for the particular types of projects and functions. It would help project managers in making consistent, appropriate decisions, related to selection of IT tools.
- The spreadsheets are very time consuming to create as well as to update and do not allow manipulation of data for decision making. Therefore, a ready software application such as EXPEDITION by Primavera systems, Inc. should be used on projects like this one which could facilitate better organized data capture at one place.

Cost Control Related changes

- A spreadsheet based system is not flexible enough for data manipulation and reporting compared to a database system. Spreadsheet based systems also take more time for reports generation compared to database systems.
- This spreadsheet based cost control system does not monitor requisitions and invoices. Therefore, this system cannot monitor the actual amount paid to the contractors and the actual progress of the project without entry of that data. This system also does not summarize change proposals, which are not converted to change orders, in the summary report.

6.3.4 Evaluation of recommendations and CMSDM

The following observations were made about the recommendations by the project manager.

- It was observed that all phases and activities of the CMSDM cannot be followed for a small project.
- The project manager agreed to the recommendation about development of corporate information architecture and educating project managers with the available IT options to manage their projects in a most efficient way.
- Observations about a cost control system were accepted in part. The project manager agreed that a use of ready software would make the whole process of cost control along with document management more efficient.

6.4 Summary

The case studies were aimed at evaluating application of CMSDM to real construction projects. Two construction projects managed by a construction management contract delivery systems were selected and their process of development of a project level information system was identified. The ultimate product of the system development process, the cost control system, was analyzed and evaluated on the basis of project requirements and the process used to develop that system.

A considerable amount of potential cost savings were observed by application of CMSDM for developing information systems. A need for corporate information technology architecture was observed in the case of small size projects.

CHAPTER 7

SUMMARY, CONCLUSION AND FUTURE RESEARCH

7.1 Summary

This thesis was inspired by the researcher's observations about the use of information systems in the construction project environment. The researcher observed a great amount of research done in the area of information systems development in the management information systems field. But this research was not communicated or applied in the construction industry, which uses information systems in different forms to manage multi-million dollar projects. An efficient information system is one of the major factors involved in the successful management of a construction project, unfortunately information systems are developed in the construction environment in a very "ad hoc" manner. This research was aimed at developing a system development methodology for a construction project environment. The research objectives were to define a structured system development methodology applicable to a construction project environment and to demonstrate its application by developing a cost control system for a domain construction project environment. This system development methodology was also evaluated by applying it to two case studies involving system development in a construction environment. The purpose of the case studies was to evaluate practical application of the proposed system development methodology to a cost control system.

This research was initiated with a literature review, which covered different system development methodologies proposed by various researchers. No system development methodology was found to be tailored for a construction project environment. The literature review found discussions on different issues related to computer applications and management of computer resources in construction. It was observed that all of the research work in this area has been done in a very fragmented manner without looking into the core issue of system development.

The information system development environment in the construction industry was described before defining the system development methodology. Different subsystems that make up a construction management information system were identified, and were classified on the basis of various parameters such as managerial activities and the core functions of those subsystems. This classification can be used to identify the combination of the subsystems required in a particular project environment for a particular system owner. The different people involved in system development such as the system owner, the system users, the system designer and the system builder were identified from the construction project perspective and their roles and activities were explained. Different constituents of an information system such as data, process, interface and geography were described from a construction project perspective.

After identifying the system development environment, reasons for system development and instances of such development efforts in the construction industry were identified. After identifying the reasons for information system

development, a structured system development methodology was defined and its components were identified. This methodology consists of the processes of system development, techniques used in those processes, and the CASE tools used to facilitate a system development process. Different types of processes and techniques were identified, and the process, technique and CASE tool most applicable to the construction project environment were selected.

A Construction Management System Development Methodology (CMSDM) was developed in the form of phases and activities. It was observed that this methodology might not be applicable to all project environments and that changes need to be made based on project and process variables. These variations for each activity in different project environments were identified. After defining the CMSDM, this methodology was applied to a hypothetical construction project environment to develop a cost control system. In order to understand the domain project environment, a Construction Management (CM) contract delivery system was defined and services provided by CM firms were identified. This demonstration included each system development activity and the deliverables from those activities.

Two case studies were conducted to evaluate the application of CMSDM in real construction project environments. The process of the system development and the cost control system were observed on these projects and the processes and products were evaluated on the basis of performance of the system. Then the professionals on these construction projects reviewed the

CMSDM and their views about the application of CMSDM were noted in this thesis.

7.2 Conclusions

On the basis of this research work including literature review, structured system development methodology and the case studies, the following conclusions can be derived. These are divided into the following three parts.

- System development methodology**
- Cost control system**
- Case Studies**

7.2.1 System Development Methodology Related Conclusions

- Every construction project has unique information system requirements. Based on these unique requirements, an information system should be developed as a combination of information subsystems such as document management, cost control and time control.**
- In most cases, an information system is not developed in a structured manner. An information system is developed according to the organizational standards based on past experience rather than on the unique requirements of the project. This results in an inefficient system which generally does not satisfy all project requirements in an efficient manner. The CMSDM developed in this thesis should be applied to all system development efforts with some changes based on the project and system variables. It is more important to go through all**

detailed phases and activities of CMSDM for a large size project, which has more unique project requirements. This methodology also acts as a check list for new project managers for designing information system. Project managers can save considerable amounts of time during construction operations by spending some more time on following a structured approach of system development during the project mobilization period.

- The structured system development methodology can not only help the system analyst in developing an information systems for construction projects, but also educate system owners and system users for better communication related to system requirements with system developers.
- Considering the general trend of using commercially available software products in other industries, the construction industry should also start using more of the commercially available software products. There are advantages in using commercially available software packages. Most importantly it standardizes the process of doing business in the industry. This would help everybody by reducing the efforts required to coordinate procedures between different organizations. But software packages, which use the best practices in the industry, need to be evolved so that all can follow best practices. These off the shelf packages are economical and take less time to configure to the unique project requirements compared to developing a completely customized system. Also, these packages can be used in multiple projects which can help organizations in standardizing their application architecture. Recruiting also becomes easier due to the availability of the required skill-set in the market.

- System development methodology in a complex and unique construction project environment should use an iterative system development process. The methodology should use data oriented techniques due to the emphasis on reports generated for decision making. CASE tools need not be used, as scope of the system development is generally too small to justify usage.
- One of the reasons behind this thesis was to develop a methodology most applicable to the construction project environment. It was observed that most of the generic methodologies also apply to the construction project environment. Therefore, the main phases and activities do not change in CMSDM but their orientation and application change based on the project and process variables. The project variables are whether or not a system is developed for a new construction project or a modification of the existing system. The process variables are selections of particular applications, reporting application, and user access to the system.
- Most construction organizations are involved in the construction of small size projects. These organizations need to develop an organizational information technology architecture which can guide them in selecting appropriate IT tool according to the project requirements.

7.2.2. Cost Control System Related Conclusions

- Cost control from the owner's point of view is of two parts:
 - A. To monitor actual expenditures compared to the actual progress.

B. To monitor changes in the scope of the project compared to the budget and contingencies of the project.

- **It is essential to identify the level at which project costs are monitored and controlled. This level is normally at the bid pack level or cost account level. In the case of large contracts with a larger size of individual bid packs, cost codes are used by further dividing bid packs for better monitoring of different project components. Project progress should also be monitored at the same level as the cost control system for a common level for monitoring cost and time.**
- **One of the factors which affects the design of a cost control system is the contract delivery system used in a construction project. In the case of a CM project with cost plus fee contracts with the contractors, the cost control system designed for CM firms also needs to analyze resource consumption by the contractors. In the case of CM projects with lump sum contracts with the contractors, the cost control system need not consider consumption of resources by contractors. In the case of design-build projects, cost control systems can be designed during the design phase of construction project to allow a fast track approach.**
- **Design of a cost control system depends on the user requirements, which again depend on the various factors such as project size, unique project requirements and complexity. The sophistication of a cost control system varies from a customized online application designed for a client-server environment with an ability to prepare customized reports to a spreadsheet developed according to the project requirements. With all this sophistication of the system,**

it has a price tag attached to it and the system developer needs to consider the tradeoff between the features provided by the system and the costs associated with it. The cost control system should not be evaluated based on its sophistication but it should be evaluated on the basis of fitting the project requirements. Management of a developed system should be considered before making decisions about the cost control system.

7.2.3 Case Study Related Conclusion

- Users of information systems in construction projects change during the life of the construction project. These users are project managers and project engineers who use the system for decision making. The users have a wide range of computer skills from low to moderate. Therefore the system should be designed to be user friendly, for the lowest level of computer skills incorporating a graphical user interface. The system should be supported with proper documentation and the users should be trained for using the system. Due to the popularity of the Internet, people are more comfortable with web interfaces. Therefore, a web based user interface may be appropriate for the project level. Web based interfaces can also be used to develop more user-friendly applications and interfaces within applications.
- Normally a project director or senior project manager or the highest decision-maker in the construction project acts as a system owner. Project managers, project engineers, schedulers, contract expeditors act as system users. This again depends on the size of the project. In the case of a medium to

large size project, the project owner also acts as a project user and gives system requirements at all the levels. In small projects, the project manager acts as a system owner, principal user and also system developer. Normally, in the construction project environment, a single person acts as a system analyst, system designer and system developer. Many times in small to medium size projects, the system is developed by the system users and therefore all activities of system owner, user, designer and builder are done by a single person. Systems developed in an "ad hoc" manner are generally not technologically advanced and use old tools such as spreadsheets to develop systems. Table 7.1 shows the different types of construction projects and their use of IT applications. It also shows the futuristic adaptation of IT applications by types of construction projects.

- The system developer's knowledge about the construction industry helps in communication and also affects the quality of the product. The selection of the system developer depends on the computer literacy of the system users Table 7.2 explains the combination of minimum skill sets of system developers, and system user. Table 7.2 represents two combination of skill-sets represented by two rows. The first row represents the fact that system users with high computer skills can work with system developer with moderate system development experience but high construction experience. The second row represents the fact that system users with low computer skills need to have system developer with high system development experience and low construction experience.

Table 7.1 Range of Construction Project and System Solutions

Size of Project	Small	Medium	Medium - Large	Large
Project Organization	Single project manager	Single project manager with some assistants	Senior Project Manager and project engineers	Senior project manager, project managers & project engineers
People involved in system development	Project manager acts as a system owner, user, designer and builder	Project manager acts as a system owner, user, designer and builder	Senior project manager acts as a system owner and user and system analyst acts as a system designer and builder	Senior project manager acts as a project owner; project managers act as a system users and system analyst acts as a system designer and builder
System development process	Classical Project Life Cycle	Structured Project Life Cycle	Iterative Structured Project Life Cycle	Iterative Structured Project Life Cycle with prototyping
System Requirements	Standard	Standard	Some customization	Unique
System Architecture: Current	Spreadsheet based system designed & build by project manager	Nonintegrated spreadsheet and market application developed by project manager.	Nonintegrated networked ready application and custom programs developed by system analyst	Nonintegrated networked custom programs and ready applications developed by system analyst.

Table 7.1 Range of Construction Project and System Solutions.**(Continued)**

Size of Project	Small	Medium	Medium - Large	Large
System Architecture: Future	More standard organizational application architecture including Ready software packages and training. Ready software packages	More standard organizational application architecture including Ready software packages and training.	More market available networked applications according to project requirements.	Combination of custom and market solution in an integrated networked environment sharing data with other project participants

Table 7.2 System Developer Selection

Combination of Skill-set	System users' Computer Skills	Developer's System Development Experience	Developer's Construction Experience
I	High	Moderate	High
II	Low	High	Low

- The system support phase is very important for the successful implementation of information system in project environment. All initial phases need to be done in a structured manner to avoid a lengthy system support phase. One of the system users should be trained to solve most of the unexpected system performance problems and prepare "ad hoc" reports.

7.3 Future Areas of Research

The following areas are suggested for future research

- Based on the CMSDM, a detailed methodology can be developed which identifies the documentation produced and standardizes the techniques that should be used for applying CMSDM. This methodology should include different variations for different project variables such as project types, contract delivery systems, and system owners. Such methodology could also be sold in the market and commercially exploited. This will make this methodology more applicable to the different industries and different types of projects.
- Demonstrating applications of CMSDM by developing a high-end comprehensive project control systems consisting of cost control, time control, and a document management system. This project control system would include all the data, processes, interfaces and geography related issues of its component subsystems.
- Benchmarking industry practices in developing information systems in a project environment. This may include identifying factors that affect people in selecting a particular approach of system development rather than the defined structure approach. This would include a survey that can capture the use of IT tools by different types of construction projects and construction organizations. Such data can be used to identify the reason behind the use of particular IT tools and their applications. This would also help in identifying

the best practices in the industry. This research can be used to identify the variable factors involved in decision making related to selection of IT tools.

The role of computers and information technology in the construction industry is going to increase considerably in the years to come. For the future challenges of constructing better, cheaper, and faster, the construction industry needs to take an approach of information technology to improve the whole process of construction.

This thesis is an attempt to attract attention of the construction industry to the role of information systems and to propose a methodology for developing information system in the construction project environment taking full advantage of the technological discoveries to achieve project objectives.

APPENDIX A

Data-Flow Diagram

Process modeling is a technique for organizing and documenting the structure and flow of data through a system's processes and/ or logic, policies, and procedures to be implemented by a system's processes. A data flow diagram (DFD) is a tool that depicts the flow of data through a system and the work or processing performed by that system. A DFD consists of the following basic concepts.

Process: A process is work performed on, or in response to, incoming data flow or conditions. e.g. Creating change orders or approving change orders.

Data Flow: A data flow represents input of data to a process or output of data from a process. e.g. Requisitions send by a contractor or checks send to a contractor.

External Agent: An external agent defines a person, organization unit, other system, or other organization that lies outside the scope of the project but that interacts with the system being studied. e.g. Contractor, or an owner for a system developed for a construction management firm.

Data Store: A data store is an inventory of data. It is an object where data is stored. e.g. A paper file or a database table.

There are several competing symbol sets for DFDs. Most of them are names after their inventors (e.g., DeMarco, Yourdon, Gane, Sarson). The example below explains use of DFDs.

Example: Figure A.1 DFD: Prepare Invoice

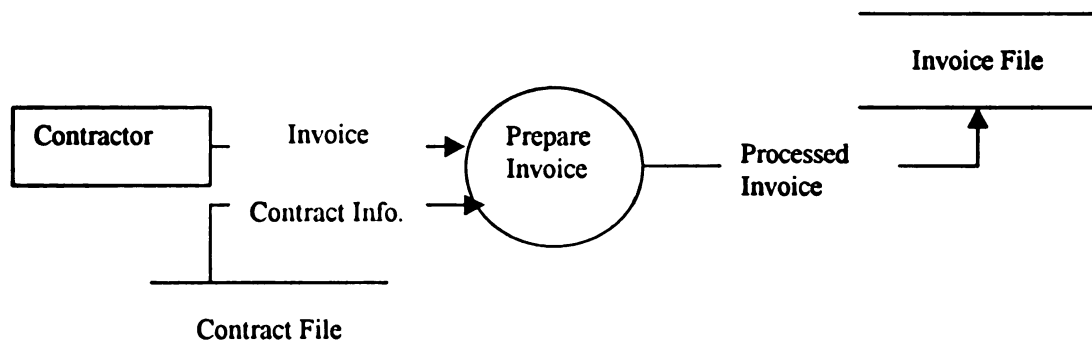


Table A.1 DFD Legends: Prepare Invoice

Legend	Explanation
<div style="border: 1px solid black; padding: 5px; display: inline-block;">Contractor</div>	Represents external agent sending information into the system
<div style="display: inline-block; width: 50px; border-bottom: 1px solid black; margin-right: 10px;"></div> <div style="display: inline-block; text-align: center;">Invoice</div> <div style="display: inline-block; width: 10px; height: 10px; border: 1px solid black; border-radius: 50%; transform: rotate(45deg); margin-left: 10px;"></div>	Represent data flow. Invoice sent from contractor to the system.
<div style="border: 1px solid black; border-radius: 50%; width: 60px; height: 60px; display: flex; align-items: center; justify-content: center; margin: 0 auto;"> <div style="text-align: center;">Prepare Invoice</div> </div>	Represents process. This represents converting invoice from paper format into an electronic format.
<div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;"> <div style="border-top: 1px solid black; border-bottom: 1px solid black; width: 100px; margin: 0 auto;"></div> <div>Invoice File</div> </div> <div style="text-align: center;"> <div style="border-top: 1px solid black; border-bottom: 1px solid black; width: 100px; margin: 0 auto;"></div> <div>Contract File</div> </div> </div>	Represent data store. This is where information is stored about particular entity. In this data store represents processed invoice.

The example explained above represents the process of accepting invoices from the contractor and processing then for storage in an electronic format.

APPENDIX B

Entity Relationship Diagram

Data modeling is a technique for organizing and documenting a system's data. The entity relationship diagram (ERD) is the most commonly used modeling technique for representing data models. ERD depicts data in terms of the entities and relationships described by the data. Entity is something about which an organization or people want to store data. A relationship is a natural association that exists between two or more entities. The relationship may represent an event that links the entities or merely a logical affinity that exist between the entities. More information can be obtained about ERD by referring to information systems literature. The following example explains the use of ERD to represent data model [Whitten & Bentley, 1998; Davis & Olson, 1986; Topper, et. al, 1994].

Example

Figure B.1 ERD: Contract and Invoice

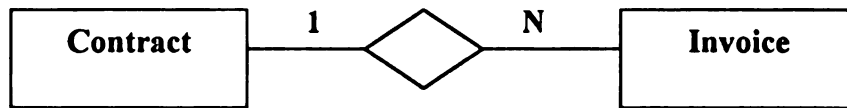
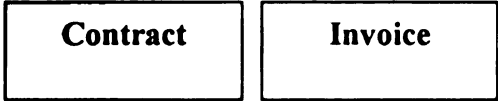
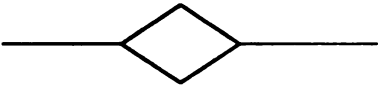
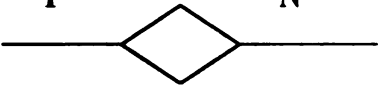


Table B.1 ERD Legends: Contract and Invoice

Legend	Explanation
	Represents the two entities between which the relationship is intended.
	Represents the relationship between two entities
	"N" represents possibility of more than one invoice related to each contract; 1 represents the fact that each invoice can have only one related contract.

Therefore, this model represents the relationship between two data entities. The model shows that each contract can have more than one invoice related to it where as each invoice can have only one contract related to it. Three possible relationships can exist between two entities. These are 1 to N, 1 to 1, and N to N.

BIBLIOGRAPHY

ASCE Task Committee (1984) "Application of Small Computers in Construction," Journal of Construction Engineering and Management, 111(3), 173-189

Adrian, J. (1981) "CM: The Construction Management Process," Reston Publishing Company, Inc.

Ahmed, I., Russel, J., Abou-zeid, A. (1995) "Information Technology (IT) and integration in the construction industry," Construction Management and Economic, 13, 163-171.

Brown, C. (1980) "Recommended Procedure for Computer Selection," Journal of Technical Councils of ASCE, 105, 319-325.

Barnes, W. (1993) "Microcomputers in Management of Construction Operations," Journal of Construction engineering and Management, ASCE, 119(2), 403-412.

Breuer, J., Fischer, M. (1994) "Managerial Aspects of Information Technologies for A/E/C Firms," Journal for Management in Engineering, ASCE, 10(4), 52-59.

Barrie, D., Paulson, B. (1992) "Professional Construction Management," McGraw Hill, Inc.

Bosserman, B., Ford, M. (1985) "Development of Computerized Specification," *Journal of Construction engineering and Management*, ASCE, 110(3).

Burger, A., Halpin, D. (1973) "Data Base Methods for Complex Project Control," *Journal of Construction Engineering and Management*, ASCE, 103(3), 453-463.

CRSS Constructors (1992) "Constructors Procedure Manual: Cost Control," CRSS Constructors, Inc.

Chris H., Tung A. (1989) "Project management for Construction," Prentice-Hall, Inc.

Curtis, G. (1995) "Business Information Systems," Addison-Wesley Inc.

Davis, G., Olson, M. (1985) "Management Information Systems: Conceptual Foundations, Structure, and Development," McGraw Hill, Inc.

EXPEDITION (1996) "Reference Manual," Primavera Systems Inc.

Fenves, S., Schiffman, R. (1979) "Quality Assurance of Engineering Software," *Journal of Technical Councils of ASCE*, 105, 57-73.

Fisk, E. (1997) "Construction Project Administration," Prentice Hall, Inc.

Gibson, G., Bell, L. (1991) "Electronic Data Interchange in Construction," *Journal of Engineering and Management*, ASCE, 116(4), 727-737.

Kostem, C. (1993) " Migration to a Networked Workstation Environment," Fifth International Conference on Computing in Civil and Building Engineering, ASCE, 1183-1189.

Krone, S. (1993) "Containing Construction Change with Computers," Fifth International Conference on Computing in Civil and Building Engineering, ASCE, 1762-1769

Lackowitz, G. (1992) "Computer Vendor-User Relationships," Eighth National Conference on Computing in Civil Engineering and Geographic Information Symposium, ASCE, 1031-1034.

Mead, S. (1997) "Project Specific Intranets for Construction Teams," Project management Journal, September 97, 44-51.

Najafi, F. (1991) "Legal Aspects of Computer Use and Measures of Software Quality and Legal Concern," Civil Engineering and Symposium on Databases held in conjunction with A/E/C, ASCE, 178-191.

Paulson, B. (1976) "Concepts of Project Planning and Control," Journal of Construction Engineering and Management, 102(1), 67-80.

Paulson, B. (1992) "Trends in Computer Application for Building Construction" *1992 Kudroff Memorial Lecture at Penn State.*

Paulson, B. (1996) "Computer Applications in Construction," McGraw Hill, Inc.

Pixley, A. (1992) "Computer Vendor-User Relationships" Eighth National Conference on Computing in Civil Engineering and Geographic Information Symposium, ASCE, 1015-1020.

Primavera Project Planner (1997) "Reference Manual," Primavera Systems Inc.

Russel, A. (1993) "Computerized Daily Site Reporting" Journal of Construction engineering and Management, ASCE, 119(2), 385-401.

Sadri, S.,Roosbeh, K. (1993) "Construction Information Management," Fifth International Conference on Computing in Civil and Building Engineering, ASCE, 1754-1761

Schultz, R. (1997) "Information Systems and Architecture Practices," [Online] Available <http://www.co.calstate.edu>

Stanton W., Willenbrock, J. (1990) "Conceptual Framework for Computer-based Construction Safety Control," Journal of Construction engineering and Management, ASCE, 116(3), 383-398.

Stukhart, G. (1989) " Bar-Code Standardization in Industrial Construction," Journal of Construction engineering and Management, ASCE, 116(3), 416-431.

Syal, M. (1992) "Construction Process Knowledge Model to Assist Method Selection in Project Planning," Ph.D. Dissertation presented to the Pennsylvania State University, University Park, PA.

Syam, M., Willenbrock, J. (1991) "Computer-Integrated Design Drawing, Cost Estimating, and Construction Scheduling," HRC Series No. 11, Housing Research Center, The Pennsylvania State University, University Park, PA.

Tenah, K. (1986) "Construction Personnel Role and Information Needs," Journal of Construction Engineering and Management, 112(1), 33-48.

Tenah, K. (1984) "Management Information Organization and Routing," Journal of Construction Engineering and Management, 110(1), 103-118.

Terry, P. (1993) "Using Computers to Competitive Advantage: Philosophy and Example," Fifth International Conference on Computing in Civil and Building Engineering, ASCE, 1105-1113.

Thomas, J., (1991) "Managing Computer Resources in Engineering Firms," Civil Engineering and Symposium on Databases held in conjunction with A/E/C, ASCE, 167-177.

Tonias, C. (1992) "Computer Vendor-User Relationships," Eighth National Conference on Computing in Civil Engineering and Geographic Information Symposium, ASCE, 1007-1014.

Whitten, J., Bentley, L. (1998) "Systems Analysis and Design Methods," McGraw Hill, Inc.

Williams, T. (1994) "Applying Portable Computing and Hypermedia to Construction," Journal of Management in Engineering, ASCE, 10 (3), 41-45.

Yourdon, E. (1989) "Modern Structured Analysis," Prentice-Hall, Inc.

Zapalac, R., Kuemmler, K. (1994) "*Establishing Management Information System for Multiproject Programs*," Journal of Management in Engineering, ASCE, 10(1), 37-42.

Zaremba, C. (1993) "PC Networking - A Case Study," Fifth International Conference on Computing in Civil and Building Engineering, ASCE, 1867-1873.